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EVALUATION OF LIQUID FUEL SPACE HEATERS: STANDARD MILITARY, DEVELOPMENTAL, AND FOREIGN

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UNITED STATES ARMY
NATICK RESEARCH and DEVELOPMENT COMMAND
NATICK, MASSACHUSETTS 01760

Aero-Mechanical Engineering Laboratory

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER 14 NATICK/TR-79/021	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) 6 EVALUATION OF LIQUID FUEL FIELD SPACE HEATERS: STANDARD MILITARY, DEVELOPMENTAL AND FOREIGN		5. TYPE OF REPORT & PERIOD COVERED 9 Final rept. Oct[redacted]75–Oct[redacted]78 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) 10 William Nykvist		8. CONTRACT OR GRANT NUMBER(s) 12 84
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Natick Research and Development Command Aero-Mechanical Engineering Laboratory Natick, MA 01760		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 16 [redacted] 1L162723AH98 AF, 007
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Natick Research and Development Command Aero-Mechanical Engineering Laboratory Natick, MA 01760		12. REPORT DATE 11 Oct[redacted]78 13. NUMBER OF PAGES 83
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) 17 AF		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release, distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

HEATING	HEATERS	LIQUIDS
FIELD HEATING	TENT HEATERS	OXYGEN
COMBUSTION	LIQUID FUELS	
COMBUSTION (LIQUID FUELS)	FUELS	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report covers research intended to develop an awareness of the design problems in liquid fuel field space heating and to investigate alternative design concepts. Tests were carried out on 13 heaters of which 7 were the experimental/developmental type. Results indicate superior performance is achieved by burners which employ hydroxylative combustion, which is slower, more complete combustion where the oxygen is admitted in stages or is diluted by exhaust gases. It is recommended that prototypes of two heaters which incorporate this type of combustion, a triple-stage heater and a return-stack heater, be built and field tested.

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INTRODUCTION

In military field operations use of electrical power is limited to communications and other essential functions. Space heating, cooking, and lighting are provided by non-electrical devices. Cooking and lighting appliances use gasoline in pressurized tanks to provide a clean flame. Space heating is accomplished with either solid or liquid fuel, the latter (gasoline, turbine fuel, or diesel fuel) in heaters using vaporizing burners and gravity flow of fuel.

Although domestic oil heating first began in about 1880, it was the First World War that was in a large measure responsible for the start of the domestic oil burner industry. Coal was the universal fuel then, and was in short supply due to the war. An ample supply of oil and a long coal strike in 1923 fostered a rapid increase in use of oil burners.

It was in the 1920's that the natural draft vaporizing pot, which had been in use for years, was improved by the addition of an electric blower for combustion air. Soon to follow was the introduction of atomizing burners – the rotary types and then the low and high pressure gun types.

For the last three or four decades, little (if any) commercial attention has been focused on non-electrical oil burners. They seem to have gone the way of the horse and buggy. In Europe, however, where oil burning technology has not advanced at the rate it has in the United States, a substantial percentage of residential and industrial space heating is still done with non-electrical vaporizing heaters. European technology in this area is more advanced; the triple-stage burner, developed in the 1960's in Holland, is a vaporizing-type burner with much better performance than pot burners.

The operational demands placed upon military heaters are much more severe than on domestic heaters. Domestic oil burners are generally designed to burn one fuel at a specific flow rate with a blower providing the proper amount of combustion air and a damper to regulate the draft. In the field, military heaters must be able to burn solid fuel, gasoline, kerosene (turbine fuel), and diesel fuel; liquid fuel operation must be over a wide range of flow rates (e.g., 8 to 40 ml/min). The natural draft varies considerably in wind gusts even when a flue cap, designed to minimize draft fluctuations, is used.

The two United States military field space heaters, the M41 or potbellied stove, and the M50 or Yukon stove, are essentially unchanged from the original designs introduced in 1941 and 1950. Both heaters have some shortcomings and have difficulty burning fuel cleanly. As a result, complaints are frequently received from the users in the field. These complaints range from poor performance to safety hazards. The biggest problem seems to be excessive smoke output and soot deposits resulting in plugged stacks and frequent cleaning, a very objectionable task.

This report covers research intended to study the design problems in liquid fuel space heating and investigate alternative designs. Tests were carried out on 13 heaters, including 7 experimental/developmental types.

The goal of this research was to come up with a heater that could provide a minimum of 14.6 kW (50,000 Btu/hr) output, and could operate with a Bacharach smoke reading of #3 or less with gasoline, kerosene, and diesel fuel. The heater should be capable of self-storing all components, be physically stable, and be incapable of being overfired.

THE COMBUSTION PROCESS

There are two types of combustion of interest in vaporizing burners, hydroxylative and carbonic. In carbonic combustion, high temperatures break the hydrocarbon molecules very rapidly into carbon and hydrogen, which burn independently. The hydrogen combines explosively (and noisily) with oxygen and the slower oxidizing carbon does not burn completely. This type of combustion is characterized by a yellow flame, caused primarily by radiation from the unburned incandescent carbon. As the carbon particles cool near the tip of the flame, they change to an orange color, and finally turn black at the tip. The black unburned carbon appears as smoke or soot; soot will readily deposit on a cooler surface.

In hydroxylative combustion, the hydrocarbons absorb oxygen in successive stages, each stage resulting in the formation of hydroxyl (OH) groups. The intermediate products are alcohols and aldehydes. A process termed aldehyde degradation occurs; aldehydes have successive CH_2 groups picked off in each step of the chain reaction, forming one CO and one H_2O each time the aldehyde is degraded. The CO is oxidized to CO_2 and, in doing so, colors the flame blue. After several degradations, the end result is CO_2 and H_2O, with complete, clean, quiet combustion. The oxidation process is slow in comparison to that of carbonic, and cool enough to prevent the hydrogen/carbon breakdown of carbonic combustion. No soot or smoke is generated.

More information about combustion can be obtained from references 1 and 2.

[1] M. L. Smith and K. W. Stinson, Fuels and Combustion, McGraw-Hill, 1952, pp 128–137.

[2] F. H. Faust and G. T. Kaufman, Handbook of Oil Burning, Oil Institute of America, 1951, pp 174–176.

BURNER PERFORMANCE

There are three basic indicators of burner performance. They are the smoke reading, percent CO_2 and stack temperature.

Smoke generated due to incomplete combustion is measured by means of the Bacharach Smoke Scale. This scale is used in ASTM D 2156, Method of Test for Smoke Density in Flue Gases from Distillate fuels. A known volume of flue gas is filtered through white filter paper and the resultant shade of gray or black is compared to a standard on a scale of 0 to 9. The significance of the scale numbers, with regard to domestic furnaces, is interpreted by Bacharach Instrument Company in Table 1.

TABLE 1

Bacharach Smoke Reading and Burner Performance

Smoke Scale Reading	Burner Performance
1	Excellent – Little, if any, sooting of furnace surfaces.
2	Good – May be slight sooting with some types of furnace but little, if any increase in flue gas temperature.
3	Fair – Substantial sooting with some types of furnace but rarely will require cleaning more than once a year.
4	Poor – This is a borderline smoke – some units may soot only moderately, others may soot rapidly.
5	Very Poor – Heavy sooting in all cases – may require cleaning several times during heating season.
6	Extremely Poor – Severe and rapid sooting – may result in damage to stack control and reduce overfire draft to danger point.

Smoke readings of 7, 8 and 9 are not listed by Bacharach probably because they are rare in domestic burners. Very heavy sooting occurs at these smoke readings. A reading of 9+ is used in this report; it refers to a much heavier smoke than number 9, smoke which can be seen pouring very heavily out the end of the stack. The higher

smoke readings, 6 through 9, denote situations in which exhaust gases are smoky enough to be seen against the sky at the end of the stack. The higher the reading, the easier it is to see the exhaust.

In reference 3, measurements of the weight of soot per $2.83m^3$ ($100\ ft^3$) stack gases were correlated with Bacharach smoke number. The fuel lost as soot for smoke numbers 1, 4, and 9 was 0.001, 0.01, and 0.1 percent, respectively. Thus, for a smoky heater operating at #9 smoke, only 0.1% reduction in efficiency would be experienced. For this report, losses due to incomplete combustion are ignored. Further discussion about incomplete combustion, its relationship with percent carbon monoxide, and how it affects efficiency can be found in Appendix B.

Percent CO_2 in exhaust gases is a measure of excess combustion air. Perfect combustion, where fuel is oxidized completely with just the exact amount of air, would result in 15.06% CO_2. See Appendix B for derivation of this result. Any excess air will lower the percent CO_2 in exhaust gases by dilution. The relationship between percent CO_2 and percent excess air is shown in Table 2, using equation (B8) from Appendix B.

[3] R. Hunt and R. Biller, "A Gravimetric Correlation of Smoke Measurements," Proceedings: American Petroleum Institute on Distillate Fuel Combustion, March 1961

TABLE 2

Percent CO_2 and Excess Air

CO_2 %	Excess Air %
15.06	0
14	7
13	15
12	24
11	34
10	47
9	63
8	82
7	107
6	141
5	187
4	257
3	374
2	608
1	1308
0.5	2709

With a low exhaust gas CO_2 percent, much more air passes through the heater than is necessary. This reduces the temperature and size of the flames and decreases efficiency. Most authorities on combustion regard adjustment of excess air in furnaces to produce from 10 to 12 percent CO_2 as sound practice. Adjustment within these limits will insure against changes in fuel or in combustion conditions acting to cause a smoky flame with attendant incomplete combustion.

Stack gas temperature is an indicator of how much heat is transferred from the heater body. The lower the stack gas temperature is for a given firing rate, the more heat has been transferred prior to gases reaching the stack. Heaters with greater surface area have relatively low stack gas temperatures and higher efficiencies.

Of these three indicators, only percent CO_2 and stack gas temperature are used in the calculation of heater thermal efficiency (further discussed in Appendix B).

TEST PROCEDURES AND EQUIPMENT

The tests which are the heart of this report are considered to be "field tests" rather than precise laboratory tests. Precise, carefully controlled tests on natural draft heaters are difficult to conduct due to the difficulty in controlling the factors affecting the stack draft. The stack draft is directly proportional to the stack height, barometric pressure, and the difference between the inverse of the average stack gas temperature and the inverse of the outside air temperature. A precise, carefully controlled test would require control over the outside temperature as well as testing over a broad range of outside temperatures, e.g., $-17°$, $-7°$ and $4°C$. This degree of precision and control is not necessary for this report, and indeed would be difficult and costly to attain.

In actual field operation, heaters are subject to variations in draft due to all the factors mentioned above as well as wind. A good field heater should be as insensitive to variations in draft as possible.

The field tests of this report were run under conditions typical to those under which they might actually be used. The tests were conducted as much as possible during the winter season in a small shelter outside in an open field. Due to factors beyond our control, some of the heaters had to be tested in the spring or fall. The shelter used was an excess MUST (Medical Unit, Self-Contained, Transportable) ward container, measuring 3 m wide, 3.5 m long, and 2 m high. It has a 45-cm-diameter hatch in the roof through which stacks protruded during tests. On days when winds were strong or excessively gusty, no tests were run.

Temperatures were measured with a Leeds and Northrup 20-channel recorder, Speedomax model G. The range is 0 to 1500°F (−17.8 to 816°C); iron-constantan thermocouples were used. Inner stack thermocouples were sheathed in ceramic while body thermocouples were attached to the heater body with #4 sheet metal screws.

A Fyrite model CND CO_2 tester was used to measure percent CO_2. Smoke readings were taken with a Bacharach True Spot Smoke Tester, model RCC–B. Draft was measured with a Dwyer model 400 draft gage, and wind was measured with a hand-held Dwyer wind meter with 2 to 10 mph and 10 to 66 mph scales. Draft measurements were taken through a 6.3-mm diameter steel tube welded to the first stack section. The tube was 33 cm above the bottom of the stack section, and care was taken to make the tube flush to the inside of the stack. Smoke and CO_2 measurements were taken through a 6.3-mm diameter hole opposite the draft tube. Fuel was stored in a standard 5-gallon GI can with an outlet pipe and valve welded near the bottom. Fuel flow rate was measured using a 100-ml burette, with bottom feed and exit, and a stopwatch. A valve between the fuel can and burette was used to stop fuel flow from the can to the burette, the time for the fuel level in the burette to drop 10 ml was measured, and the resulting rate in ml/min was looked up in a previously made table. For each fuel flow rate tested, outside wind was checked with the wind meter for about 20 seconds. The estimated average wind velocity for this period was recorded.

In a typical test, thermocouples are first mounted in several places on the heater. The fuel line is attached to the burette, and the draft line is attached to the stack. The heater is fired and set for the low or start setting, and run until temperatures stabilize, as indicated on the temperature recorder. After stabilization, fuel flow rate, draft, CO_2, smoke, wind, ambient and shelter temperature, and heater temperatures are recorded. The fuel valve is turned to the next setting, and the procedure repeated. The heater is allowed to cool between tests.

Original data for this report is located in NARADCOM Laboratory Notebooks 6741, 6901, and 7232.

TEST RESULTS AND DISCUSSION

A. Standard Military Field Heaters:

1. **M1941** – The M1941 (or M41) potbellied stove as pictured in Figure 1 was introduced to the military in 1941 in response to an urgent need for a field heater during World War II. The burner was designed by James Breese of Breese Burners, Inc., who had originally worked with pot burners as heaters for steam driven automobiles. He later perfected the vaporizing pot burner for space heating and went into the pot burner business when interest in steam-engine automobiles waned.

The M41 can burn gasoline, kerosene, diesel fuel, and also solid fuel when the burner pot is replaced with a grate assembly. It is rugged, stable due to its low profile, and the top and bottom sections can be nested for shipping. The burner/constant level valve assembly is designed so that if the flames were suddenly extinguised, the equilibrium fuel level in the bottom of the burner would be below all air holes, and no fuel leakage would occur.

Shortcomings of the M41 are the inability to self-store all components and the frequent production of excessive smoke and soot. Some complaints have been made that it does not put out enough heat.

The M41 is 47 cm in diameter, 43 cm high, and the burner pot is 25 cm in diameter. It weighs 15.9 kg including six stack sections, draft diverter, and constant level valve.

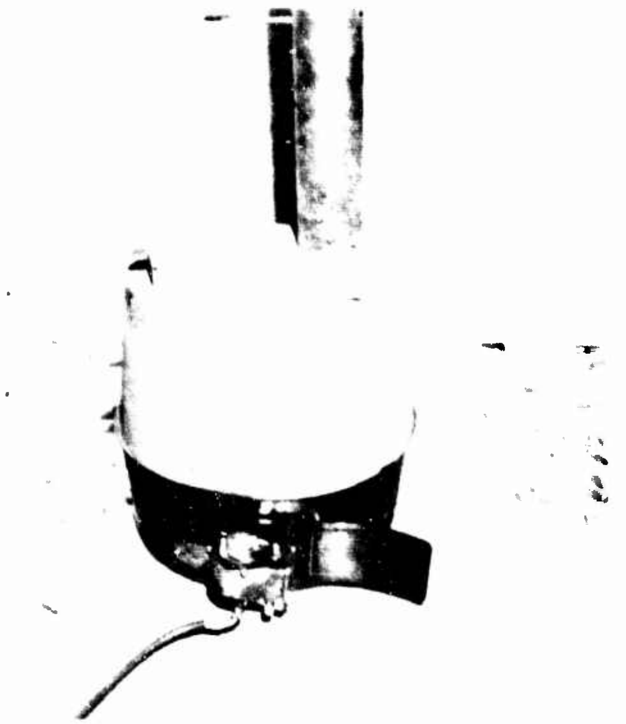
The Technical Manual for the heater, reference 4, claims a maximum heat output of 13.2 kw (45,000 Btu/hr). Test results from Table A1 of Appendix A are summarized with respect to maximum output in Table 3.

Table 3

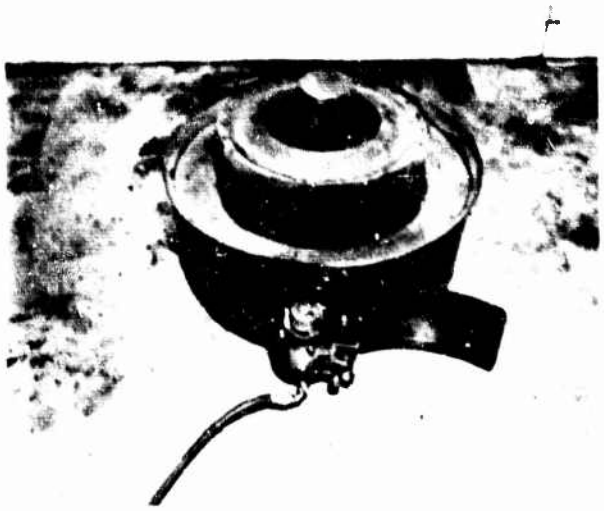
Maximum Output of M41 Heater

Fuel	Max Fuel Rate (ml/min)	Fuel Input kw	Fuel Input Btu/hr	Smoke Number (Bach.)	Average Thermal Efficiency (%)	Heat Output kw	Heat Output Btu/hr
Gasoline	50	29.5	100,650	5 to 9	56	16.5	56,360
Gasoline	41.4	24.4	83,340	2 to 8	52	12.7	43,340
Kerosene	42.8	26.2	89,530	4 to 8	54	14.2	48,350
Diesel	37.5	24.7	84,410	5 to 8	52	12.9	43,890

[4]TM 10–4500–200–13, Heaters, Space, Radiant Type, Portable, M1941 & 1950



Assembled Heater



Lower Half

Burner With Upper Air Tube Removed

Figure 1. M41 Space Heater

This table indicates the M41 is somewhat shy of its rated capacity. The two fuel flow rates listed for gasoline are for settings 9 and 7 on the constant level valve. When using gasoline, it is recommended a setting of 7 not be exceeded; however, this instruction is often ignored, so the output for setting 9 is included.

A peculiar characteristic was observed in testing the M41 heater. The first two tests of Table A1 using gasoline were in an ambient temperature of 0 to 3°C; the second two tests with gasoline were in an ambient temperature of 12 to 19°C. At gasoline flow rates above 30 ml/min, the smoke readings in the warmer ambient were consistently much higher. This characteristic was also observed with kerosene and diesel fuel. The added stack draft at the colder ambient temperatures presumably is the difference.

In this report, heater output is determined by multiplying the heat content of the fuel burned by the efficiency. The mechanism of heat transfer, i.e., what percent is convective and what percent is radiative, is not measured, as it would be quite difficult. All the heat transferred from the heater, except stack losses, occurs within the tent or shelter, and can be regarded as effective heater output.

The thermal efficiency of the M41 heater at maximum fire is only on the order of 52 to 54% due to the relatively small heated surface area. The central location and raised position of the burner pot in the heater body results in flames impinging mainly the top surface so the effective heated surface area is much less than the 4660 cm^2 area of the heater top half. At high firing rates, flames actually climb well up into the first stack section. Also, the secondary air holes around the burner top rim admit air which acts as an insulating film between the combustion gases and the heater wall. The efficiency calculation is based on stack temperature measured 7 cm above the heater top surface. With the M41 heater, considerable heat is transferred from the stack prior to the flue gases exiting through the shelter roof. In one test with the M41, at high fire the stack temperature measured 2 m above the heater was 250°C lower than that close to the heater. Using this lower temperature in the efficiency calculation gave an increase in efficiency of about 15% resulting in 3.9 kw (13,270 Btu/hr) more output. Of course, all heaters will have varying amounts of stack related heat transfer. For evaluation and comparison purposes, heater output discussed in this report will not include that delivered by the stack.

An investigation of the M41 was reported in reference 5. The investigation was directed toward achieving a maximum burning rate, and an efficient smokeless combustion process. A summary of this work is:

(1) The most important mode of heat transfer from the flame to the incoming fuel is radiation, although conduction and convection do contribute in a measurable degree.

[5] A. E. Weller, "Investigation of Gravity-Fed Vaporizing Puddling-Type Burners," Contract No. DA–19–129–QM–835, Battelle Memorial Institute, Columbus, Ohio, July 1958

(2) Combustion products are recirculated from the flame to the newly vaporized fuel. Alterations of the recirculating flow were shown to have a significant effect on the operation of the burner.

(3) The rate of air flow is substantially independent of the draft and an optimum firing rate exists for minimum smoke formation.

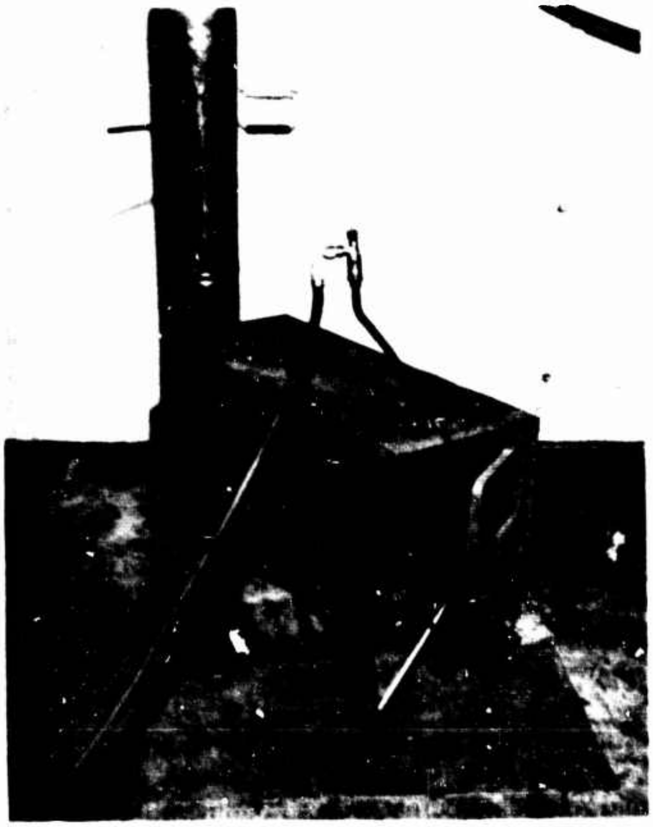
(4) Many tests were performed which led to a greater understanding of the M41: measurement and modification of air flow at specific locations, removal of pilot ring, measurment of vaporization rates, circulation patterns, pressure drops, gas temperatures, etc.

(5) Separate tests involving a homogeneous burner and an inverse diffusion flame apparatus were performed to study, in a more controlled manner, combustion processes similar to those occurring at various locations in the M41.

It was concluded that to limit smoke emission and carbon deposits, three major requirements must be attained: (1) to dilute the vaporized fuel with large quantities of oxygen-free combustion products, at least 15 kg/kg, (2) to react as much fuel as possible by the flameless combustion reaction, and (3) to maintain gas temperatures not higher than 1000°F (538°C) throughout the burner.

It was noted that the application of combustion product recirculation will have a fundamental problem that, depending on burning rate, the recirculated gases could have large or small quantities of free oxygen. This would result in a burner with an optimum burning rate with degraded performance at other rates. A possible solution offered was a staged burner designed so the larger stages begin operation as higher burning rates are demanded.

2. M1950 – The M1950 (M50) or Yukon Stove, as pictured in Figure 2 is a lightweight heater of a radically different design than the M41. It uses a top-mounted vaporizing plate burner fed by a drip valve. The burner base has several concentric grooves over which the fuel must flow prior to reaching the edge; this allows the fuel to heat up on the hot base plate and vaporize before it enters the heater. When starting the M50, the burner, of course, is cold and fuel drips down into the heater body. There it burns off the heater floor for a few minutes until the burner base is heated up. Once the burner is hot, flames emanate directly from it. The drip valve that regulates flow to the burner is simply a needle valve. A sight glass built into the valve permits rough regulation of flow by a visual count of drops. At higher flow rates, the fuel transitions into a steady stream and judgement of fuel flow can only be made by the response of the heater. The heater is noisy in operation, believed to be the result of pressure pulsations many times per second in the heater. The technical manual (reference 4) claims the burner "will operate on leaded or white gasoline" and may be adapted to burn coal or wood by covering the burner opening on the top of the heater and adding a grate. As the heater is often used to burn diesel fuel, and sometimes kerosene, tests were run using these fuels.



Assembled Heater

Vaporizing Plate Burner, Disassembled

Figure 2. M50 Heater, Yukon Stove

The M50 heater body is 24.8 cm wide, 20.3 cm high, and 60.9 cm long. Set up for operation, the heater top surface is 41.9 cm off the ground. The base section of stack supports the rear section of the heater and is attached by twisting the stack tee into three offset ear clasps. The stack is composed of five sections which are slightly tapered for nesting purposes. The assembled stack is 10 cm diameter at the top and 12.7 cm diameter at the bottom. All components of the heater can be packed into the heater interior for shipping; with the legs folded, the heater is quite compact. The total weight of the heater is 14.97 kg (33 pounds).

A heater output of 17.6 kw (60,000 Btu/hr) is stated in reference 4, and a maximum fuel consumption of 39.4 ml/min (0.625 gal/hr) is specified for smokeless combustion.

Test results from Table A2 in Appendix A are summarized in Table 4:

Table 4

Maximum Output of M50 Heater (Yukon Stove)

Fuel	Fuel Rate (ml/min)	Fuel Input kw	Fuel Input Btu/hr	Smoke Number (Bach.)	Thermal Efficiency (%)	Heat Output kw	Heat Output Btu/hr
Gasoline	37.5	22.1	75,490	8	71.5	15.8	53,980
	54.6	32.2	109,910	9+	73.5	23.7	80,790
Kerosene	31.6	19.4	66,100	8	69.5	13.5	45,940
	50	30.6	104,590	9+	71.5	21.9	74,780
Diesel	31.6	20.8	71,130	9	69	14.4	49,080
	54	35.6	121,550	9+	73	26.0	88,730

In this table two fuel rates are listed for each fuel. The lower one is the fuel rate closest to the maximum capacity without overfiring (overfiring is defined as smoke readings of 9+); the higher one is the highest flow at which the heater was tested. This heater has an overfire point for gasoline somewhere between fuel rates of 37.5 ml/min and 46.2 ml/min according to our test data. Review of test data in Appendix A indicates the M50 never attains true smokeless combustion; the lowest smoke reading for gasoline was #5. Smokeless combustion referred to in reference 4 must mean combustion below the overfire point. The overfire point for gasoline is approximately the same as the maximum "smokeless" combustion rate specified. Using the two heavier fuels, which the heater was not designed to burn, the overfire point is lower, and the heater does not attain its rated output without being overfired.

When overfired, the M50 heater really puts out a lot of heat. Many parts of the stove glow red, and heavy black smoke pours out of the stack. Since there is no mechanical upper limit to the drip valve, the flow rate we tested to is by no means as high as the heater will go. Although efficiency calculations may be suspect due to incomplete combustion and higher levels of carbon monoxide, heat output of well over 27.8 kW (94,840 Btu/hr) is easily attainable Since we didn't operate the heater long periods of time at high flow rates, no problems due to excessive soot buildup were experienced. We did note a substantial sooting of the stack, flue cap, and thermocouple placed in the stack, and readily believe statements from the field that claim the stack completely plugs up with soot over a period of time.

Comparing the thermal efficiency of the M41 and M50 heaters with gasoline at approximately 40 ml/min, the M50 at 72% is much better than the M41 at 51%. This is due to the greater heated surface area of the M50 over the M41 (6500 cm^2 vs 3460 cm^2) resulting in a lower stack gas temperature; also the M50 has a lower volume of excess air.

The M50 heater generates a lot of smoke and soot. With gasoline the lowest smoke reading was 5; with diesel fuel the lowest reading was 9. The combustion air enters all at once around the periphery of the burner. This momentary abundance of oxygen permits the rapid oxidation of the hydrogen portion of the hydrocarbon molecule and results in carbonic combustion. At higher fuel rates there appears to be a shortage of oxygen and poor mixing in the heater. The end result is a lot of unburned carbon in the form of smoke and soot which fouls the air, and eventually plugs the stack.

The basic design of the heater from a heat transfer viewpoint is very good. However, from a safety viewpoint the heater is very dangerous. It is easily tipped over since the front and rear legs are free to rotate and the width of the front legs is only 24.8 cm. It must be under constant observation since there is no provision to shut off the fuel supply automatically if the flame were to extinguish. In windy, gusty conditions the flames will occasionally reverse and shoot out of the burner opening. Many fires and some deaths have been attributed to this heater.

Operation of the M50 and M41 heaters with solid fuel is discussed in reference 6. This report describes the above heaters in detail and includes brief descriptions of coal and wood, their burning characteristics and storage problems. Recommendations relating to changes in present equipment and the need for additional equipment are also included.

[6] C. J. McKeown, "Operation of Military Field Heating Equipment Using Solid Fuels," Technical Report 76–61–AMEL, March 1977 (AD A037121)

B. Foreign Heaters

1. Triple-Stage Heater, Type 1 (United Kingdom Paraffin Field Heater):

This heater was developed by Stores & Clothing Research & Development Establishment (SCRDE), Colchester, England, to fill a need identified during a winter NATO exercise in Norway in 1969/1970. Since a heater unit was desired for the winter of 1970/1971, and there was not enough time to go through the design and development process, a commercial British heater, the Aladdin 30T, was modified for military use. The 30T was in use throughout Europe for domestic hot air central heating; modifications were to change the design fuel from diesel to paraffin (kerosene), and to make the unit more rugged. The heater was obtained on loan under the America-Britain-Canada-Australia (ABCA) Army Standardization Agreement.

The heater, shown in Figure 3, uses a triple-stage burner designed and developed by Sesto Research Institute, Hilversum, Holland. The burner consists of three stages separated by baffles, as shown in Figure 4. Air is admitted under each baffle through carefully sized holes so the fuel is oxidized slowly, in stages. At low fuel flow rates flames occur under the first baffle, as there is enough oxygen there to support combustion. As the fuel flow increases, the flames move up until at maximum flow only flameless oxidation occurs within the burner and flames are seen only at the top row of holes. The visible flame is generally a mixture of blue and yellow.

The screen-inclosed heater is 56 cm long, 38.7 cm wide, 55 cm high, and weighs 34.1 kg (75.2 lb). A wooden box is supplied for shipment and the total shipping weight is 45.7 kg (100.7 lb). Six stack sections are provided, each 8.9 cm in diameter with an effective length of 45.7 cm. A "draught brake" measuring 15 cm diameter by 51.4 cm long, equivalent to our flue cap or draft diverter, is also supplied. All stack sections will fit within the screen inclosure for shipment. The constant level valve is a Dutch model with a maximum flow rate about half that of the one used with the M41 heater. There is a lighting tube and wick for lighting the burner. To light the burner, the constant level metering valve is turned to a low setting and the wick withdrawn periodically to see if the fuel has wetted it; if so, the wick is lit and reinserted. After about 5 minutes, the burner is hot enough to sustain a fire, and the wick is withdrawn and a cap placed on the lighting tube. With gasoline, however, it is recommended that the wick be wetted with fuel, lit, and inserted into the burner before fuel flow is started, to lessen the chance of an explosion.

The heater was tested with diesel fuel and gasoline, with results as shown in Table A3 in Appendix A. In a very unfortunate incident, the burner was mistakenly discarded by a janitor, and this precluded testing with kerosene, or further testing with the other two fuels. The capacity is less than half that of the M41 and M50 heaters. Due to the small heated surface area (2990 cm^2, which causes stack temperatures to be high) and usage of large quantities of excess air, the resulting heater efficiencies were very low. The physical design of the top of the heater, with its sloping surfaces, does not permit

Heater With Components Packed Within Protective Screen. For Shipment, Wooden Box Fits Over Screened Heater.

Heater With Screen Removed

Figure 3. Type 1 Triple-Stage Heater, (United Kingdom Paraffin Field Heater)

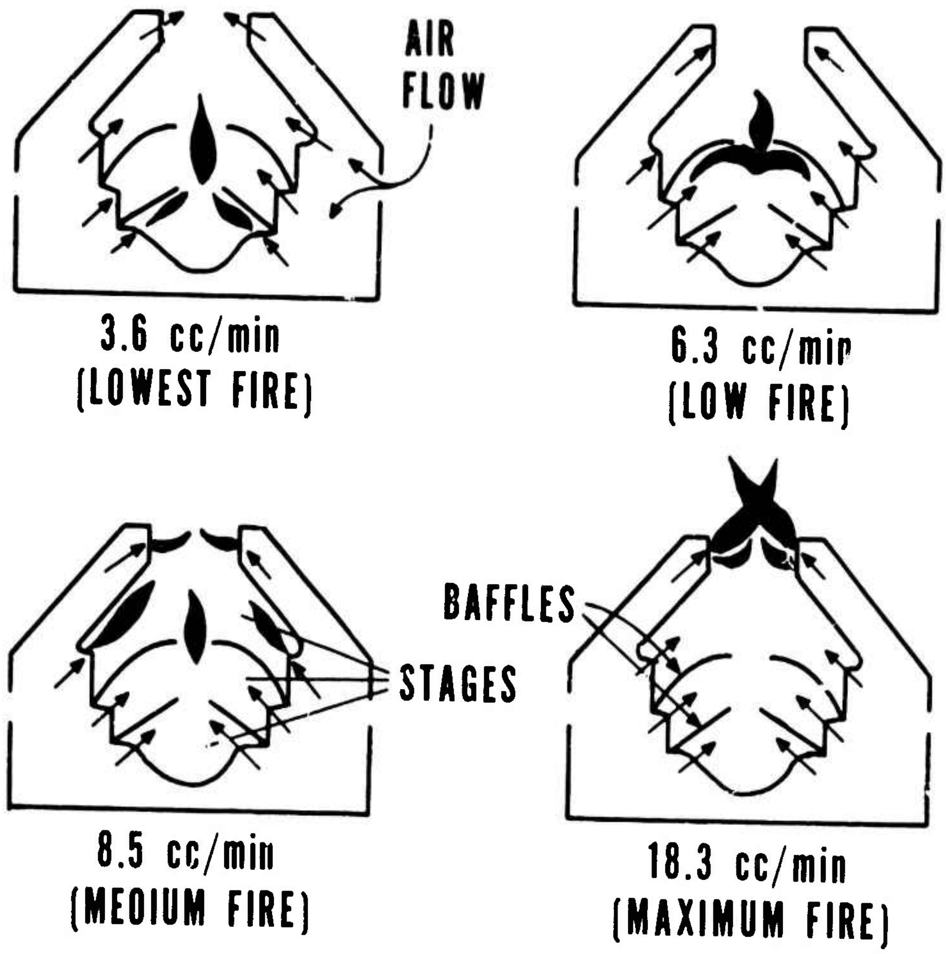


FIGURE 4. TRIPLE-STAGE BURNER CROSS SECTION-- FLAME POSITION AT VARIOUS FUEL FLOW RATES FOR THE TYPE 1 BURNER.

heating of rations or water. The smoke readings were excellent, however, with a worst value of 3. For our application, the heater is too heavy and much too low in capacity. The heater did, however, provide an introduction to the remarkable triple-stage burner burner, capable of burning diesel fuel very cleanly and quietly.

2. United Kingdom 10-kilowatt Gasoline Space Heater:

This heater was developed as a replacement for the UK Aladdin 30T Paraffin Heater, primarily due to a change in British fuel policy to gasoline. According to reference 7, this heater also was to replace the M50 "Yukon Stove" which was being used to some extent. Reference 7 states: "With both solid and liquid fuel the Yukon Stove has proved to be unreliable and hazardous to use." and, "The design of the Yukon Stove exposes the user to considerable danger through collapsinq in use."

This heater was obtained under an ABCA Army Standardization Loan of Materiel from Stores and Clothing R&D Establishment, Colchester, England. Due to its unique design, a cutaway sketch rather than a photograph is included as Figure 5. The heater has an insulated base and protective screened case which self-stores all stack sections. The air for combustion flows under the heater body through an air duct/support channel, up the rear, and into the combustion chamber through a perforated air tube. The heater is 41 cm wide, 51 cm high and 76 cm long, and weighs 42.5 kg (93.7 lb). Reference 7 claims a maximum heat output of approximately 10.5 kW (35,850 Btu/hr).

One test only was run on this heater, the results of which are shown in Table A4. The smoke readings were so inordinately high that further testing was suspended and the heater returned as the loan period was over. The results indicated good thermal efficiency with the highest CO_2 readings per given flow rate of any heater tested. It appears that there was not enough excess air to assure reasonably complete combustion.

The test results were sent to SCRDE in England. They retested the heater, found it to function normally, and returned a letter questioning our use of the draught brake. We used all four stack sections and the draught brake in our test; this put the draught brake completely outside the shelter, with the bottommost portion 1/2 m above the shelter roof. SCRDE said the draught brake must be positioned so that half of it remains in the shelter and half protrudes outside. The confusion was caused by the statement in reference 7, "When the draught brake is in use it protrudes through the shelter roof." A request to SCRDE for their retest results was not answered.

The published maximum fuel flow rate was 21 cc/min. In our test the maximum fuel flow measured was 33 cc/min.

[7]V. A. Mead, Heater, Field, Gasoline, 10 kw, Technical Note SCRDE/74/4, Stores and Clothing R&D Establishment, Colchester, England, June 1974.

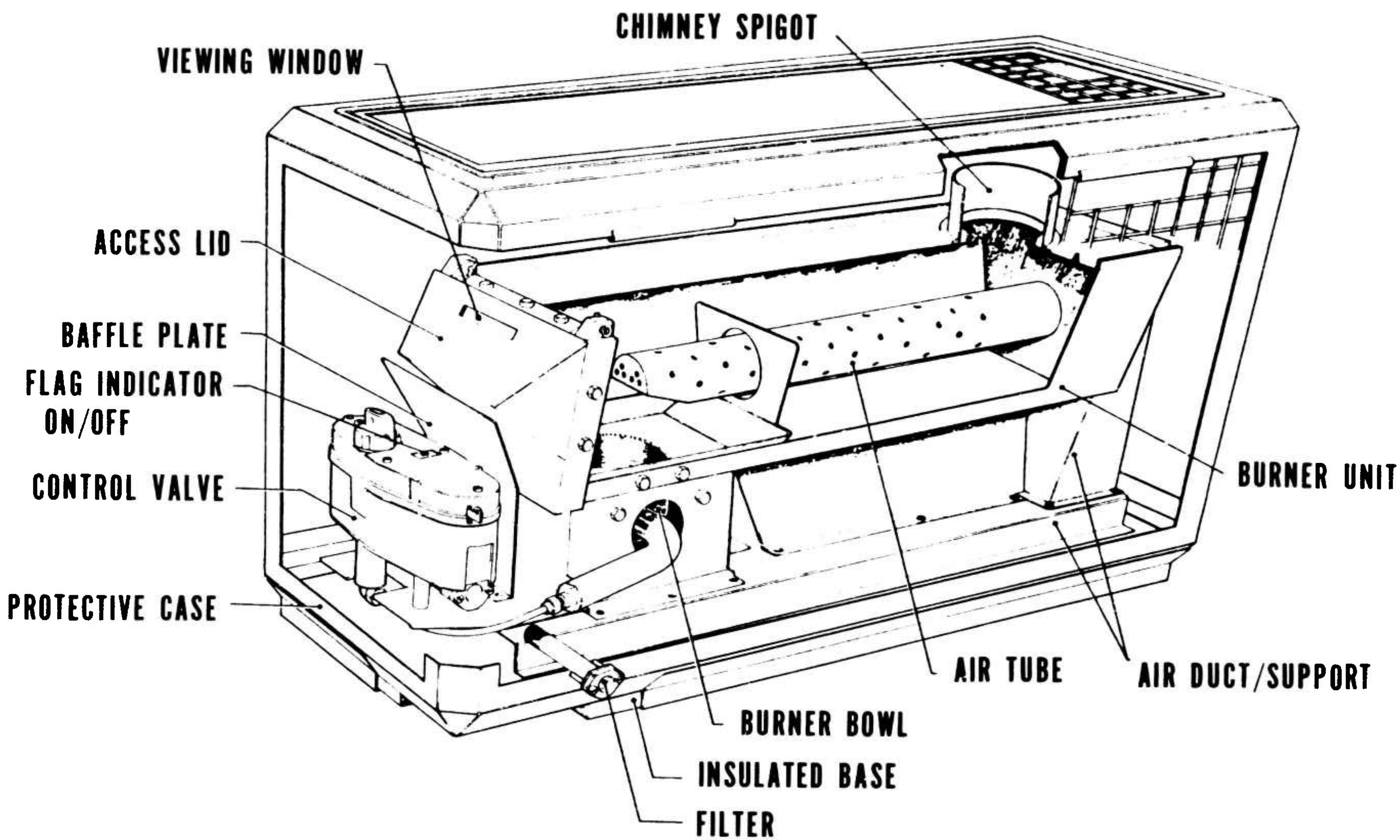


FIGURE 5. HEATER, FIELD, GASOLINE, 10 kW

The heater was not designed to burn solid fuel due to the need for timber conservation. It is compact, self storing, ruggedly built, stable and quiet burning. The single fuel restriction eliminates use of kerosene, diesel and solid fuels, and the weight is excessive.

3. **Kawabe 800S (Japanese):**

This heater was purchased from Kawabe Oil Stove Mfg. Co., Ironai, Otaru shi, Japan. Kawabe had claimed their heaters feature a double combustion chamber which makes them very efficient. The heater is pictured in Figure 6 and a cross section sketch identifying key elements is shown in Figure 7.

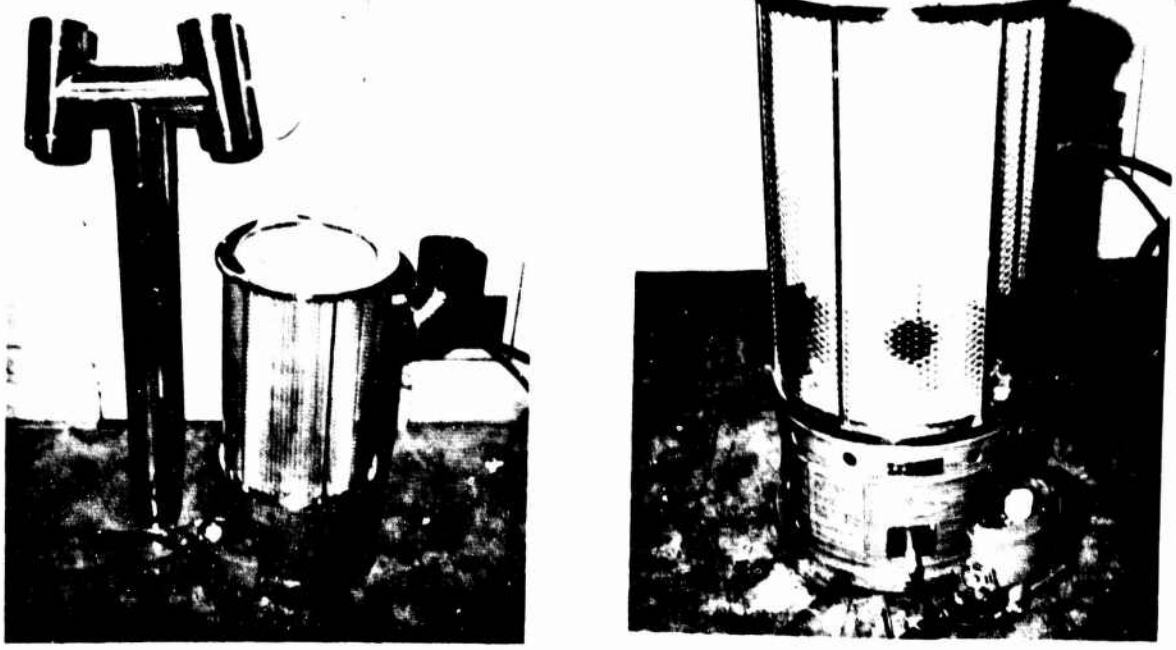


Figure 6. Kawabe 800-S Heater

As seen in Figure 7, air flow into the burner pot is typical, but exhaust gases flow through a 15.2-cm hole from the inner chamber into an outer chamber, around the circumference of the heater, and into the exhaust stack. The "double combustion" is therefore really only a counterflow of hot exhaust gases.

The heater is designed to burn kerosene but was tested with all three fuels. The heater is 69.5 cm high and 33 cm in diameter excluding protrusions of the constant level valve and exhaust stack, and weighs 21.4 kg (47.2 lb).

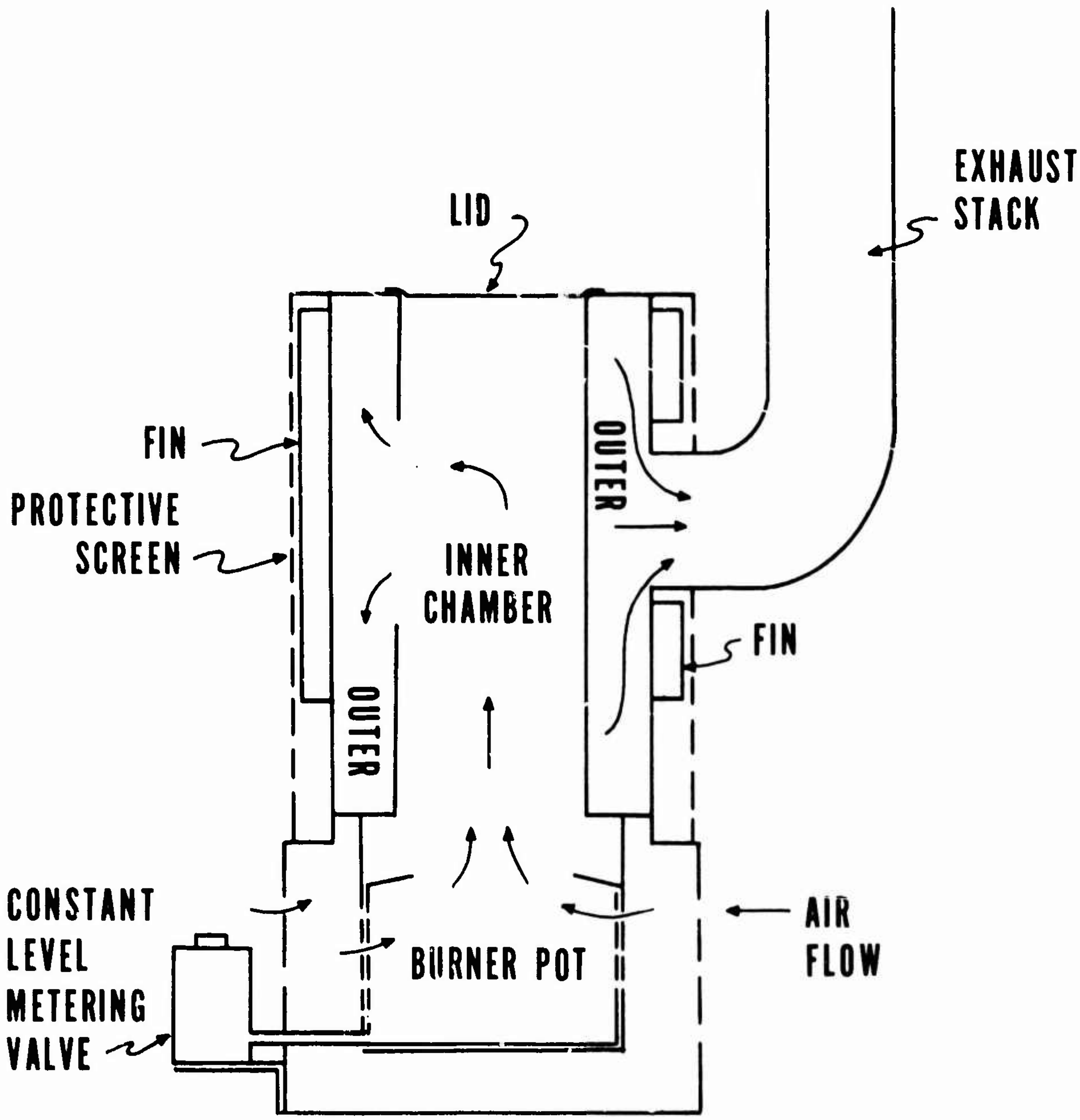


FIGURE 7. KAWABE 800-S HEATER CROSS-SECTION

The operating instructions claim a fuel consumption of 5 to 20 ml/min, a maximum input heat capacity of 12.0 kW (40,880 Btu/hr), and an efficiency of 70%. From this one can calculate a maximum output of 8.4 kW (28,610 Btu/hr).

Test results, Table A5, indicate smoke readings no higher than #3 with kerosene, but somewhat higher smoke readings with the other two fuels. Efficiencies at maximum fuel rate varied widely, ranging from 69% for gasoline, to 55% for diesel fuel.

Examination of test results for kerosene, the design fuel, shows a maximum value of percent CO_2 to be 8%. This is much lower than other heaters; e.g., the maximum percent CO_2 for the M41 and the M50 is 15%. At an 8% CO_2 there is 82% excess air. This serves to lower the temperature of exhaust gases by dilution and results in lower temperatures on heater surface areas and lower heat o... t. For diesel fuel, excess air at the maximum fuel rate was 162%.

In spite of the large amount of excess air, the efficiency of the Kawabe heater is equivalent to that of the M41 for kerosene. This is due to the larger heat transfer area of the Kawabe over the M41, 7056 cm^2 vs 3460 cm^2, due in part to the fins on the Kawabe heater. No statement can be made concerning any beneficial effect of the double flow of exhaust gases.

In an emergency, solid fuel could be used, as could gasoline or diesel fuel.

Kawabe's largest heater (out of stock when we made our order) the 1000S, is advertised as having a maximum output of 13.3 kW (46,260 Btu/hr) at 31 ml/min fuel flow, much closer in capacity to that of our standard military heaters.

C. Domestic Heaters

Return Stack Orchard Heater

This heater was briefly discussed in reference 5, where it was observed to be very simple and apparently clean burning. The return stack orchard heater was developed at University of California at Davis (reference 8) to eliminate the fouling and sludge formation experienced in the orchard heaters in use at that time. The heater operates on the principle that inert gases added to fuel vapors control the size of the carbon particles, and that carbon particles less than 0.5 micron in diameter promote smokeless combustion. A small carbon particle will require less time for complete combustion than a larger particle, and will lose heat more slowly by radiation and remain longer at a high enough temperature for burning.

The first test of this principle was to introduce the combustion products from one orchard heater to the bowl of another; a substantial reduction of smoke was achieved. Several experimental designs utilizing a return stack were made and tested, and the one put into commercial production is pictured in Figure 8.

[8] A. S. Leonard, "The Return Stack Orchard Heater," Agricultural Engineering, Vol 32 No. 12, December 1951, pp 655–656.

This heater is manufactured by Scheu Products, Inc., Upland, California, and is designed to burn kerosene, #1 and #2 fuel oil, and diesel fuel. The bowl averages 46 cm in diameter, is 25 cm high and holds 34 l (9 gal) of fuel. The total height is 137 cm, the stack 21 cm in diameter and the return stack 7.6 cm in diameter. Primary air enters through an adjustable air shutter while secondary air enters through the punched holes in the tapered first stack section which acts as a combustion chamber.

Figure 8. Return Stack Orchard Heater

Tests results, shown in Table A6, were with the bowl filled to a depth of 4 cm with diesel fuel. After starting, the heater burned with a pilot flame from the wad of paper used to light it for about 10 minutes. Once the heater warmed up sufficiently, the flame jumped up to the air holes in the first tapered stack section. The combustion process was very noisy and, in wind gusts, flames occasionally reversed and came out of the punched holes.

The burning rate with the primary air shutter in the closed position is approximately 30 ml/min, and in the open position, approximately 65 ml/min. Burning rate was not measured during our test.

Test results show smoke readings of 4 and 5 and an average efficiency of 55%. The smoke readings compare well with the claim of less than 0.1 g carbonaceous material per minute.

To extinguish the heater, the primary air shutter must be closed, a butterfly valve closed at the base of the slotted combustion section, and a tight-fitting lid placed on the top of the stack.

The heater is too dangerous, noisy, and of the wrong design to be used as a field heater for personnel but does show the improvement in performance afforded by exhaust gas recirculation. In reference 8, it was reported that the addition of an exhaust gas return system to a pot-type residential heater greatly improved its performance. This concept appears promising and worthy of investigation.

D. Experimental/Developmental Heaters

1. LWL Experimental Heater:

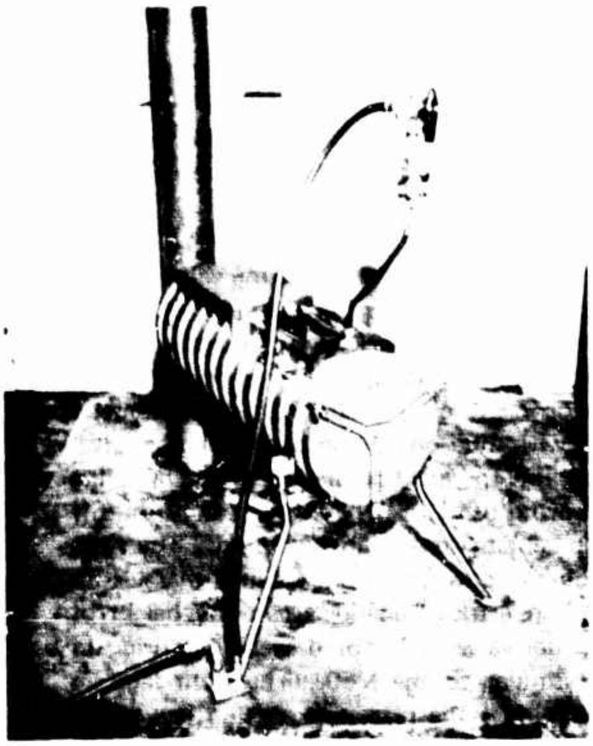
This heater, also called the "improved bunker heater" was developed in 1974 by Pennsylvania State University under contract to the now defunct US Army Land Warfare Laboratory, Aberdeen Proving Ground, Maryland. According to the contract final report, reference 9, the M50 (Yukon Stove) heater is subject to "massive production of smoke at about half its design rating and has a relatively low thermal efficiency." The procedure used to develop the new heater was to first investigate the behavior of the M50 heater and to develop modifications based upon observations of its operational behavior.

The circular burner of the M50 was claimed to be a "copious smoke generator," the source of the problem being an oxygen-deficient recirculation zone directly under the burner body and contained within the initiating flame envelope. This problem was allegedly solved by replacing the circular burner with a slotted tube burner, and increasing the "onset of smoke" from a gasoline fuel rate of 14.9 ml/min to 34.8 ml/min.

The efficiency of the heater body was reported to be increased by replacing the rectangular mild steel M50 body (15.2 by 20.3 cm cross section) with a corrugated stainless steel cylinder 20.3 cm in diameter. Also, a baffle was added at the inner top of the heater behind the slotted tube burner.

[9] W-S Shieh, R. Frank, and R. Essenhigh, "Experimental Development of an Improved Bunker Heater, Final Report," Technical Report No. LWL–74–51, Contract No. DAAD05–73–C–0192, Penn. State Univ. Combustion Laboratory, University Park, PA 16802, October 1974.

The resulting heater is shown in Figure 9.



Assembled Heater

Close-Up Of Slotted-Tube Burner

The basic design of the LWL heater is quite similar to the M50. The legs fold back along the body and the rear is supported by the lower stack section. Additional features are:

(1) Each front leg has a height adjustment so the heater can be easily leveled. The legs are angled to give more stability to the heater.

(2) In the event the heater is tipped over, a spring loaded automatic shutoff valve, located in the foot of one of the front legs, stops the fuel flow. The weight of the heater keeps the valve normally open.

(3) A safety shutoff device that will stop fuel flow if the flame extinguishes. A sealed thermocouple element is located beneath the slotted burner, which, when immersed in flames, powers a solenoid that opens a valve. The valve is normally closed when the thermocouple is cool. A reset button manually opens the valve and must be held down 30 to 45 seconds when lighting the burner to allow time for the thermocouple element to heat up.

(4) A four-position fuel metering valve with OFF, LOW or START, MED, and HIGH.

(5) A tightly sealing, removable end cap on the heater body in place of a hinged door.

Test results for this heater, shown in Table A7, indicate it smokes worse than the M50. The efficiency at maximum fire for the LWL heater is 5% less than the M50 with gasoline, 9% less with kerosene, and 17% less with diesel fuel. Both aspects of efficiency, the stack temperature and CO_2 percent, were inferior on the LWL heater in comparison with the M50 heater.

Several liabilities of the LWL design are apparent. The flow metering valve utilizes three different sized flow orifices which are brass discs with a small hole in the middle. As there is no filter in the fuel line, these holes are subject to blockage by foreign particles. In the test with gasoline, the LOW orifice did in fact plug up. A wrench and sharp object are necessary to remove and unplug the orifice disc. The spring-loaded automatic shutoff valve in the front leg could possibly foul with mud or ice and become inoperative. Since this shutoff valve is easily bypassed by attaching the fuel line directly to the metering valve, it is a good assumption the Military will avoid using it. The burner safety shutoff device malfunctioned during testing and no apparent reason could be found. The reset button had to be clamped in the open position to continue testing. Since there is no constant level valve, the rate of flow through the orifice depends upon the height of the fuel tank above the orifice. This type of fuel valve does not prevent overfiring of the heater. The heater is noisy in operation, similar to the M50. The front legs are a tripping hazard and do not lock in place, nor does the rear stack-section leg, which makes the heater physically very unstable and dangerous.

The corrugated stainless steel body did not improve heat transfer; in fact, a comparison of stack temperature for equivalent fuel rate and percent CO_2 indicates the M50 body to have a lower stack temperature. This probably is due to the comparatively lower heated surface area, 5670 cm^2 for the LWL design and 6500 cm^2 for the M50. Though the LWL heater is claimed to be 25 to 40% lighter in weight and structurally stronger, the excess cost of stainless steel over mild steel and the estimated difference in manufacturing costs were not addressed.

2. **Triple-Stage Heater, Type 2:**

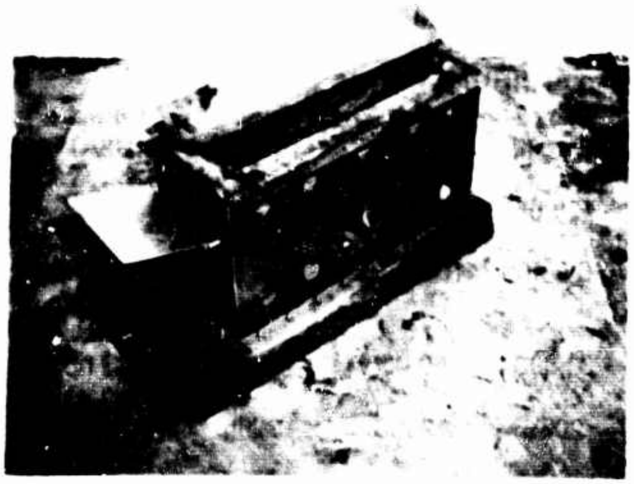
After we tested the UK Paraffin Field Heater, the developer of the triple-stage burner, Sesto Research Institute, was contacted and asked if a larger capacity burner was available. Sesto sent a brochure which advertised one with a diesel fuel input capacity of 28.6 ml/min which we will call type 2. The dimensions and design data for this burner, and a comparison of all five triple-stage burners, are shown in Table 5.

A type 2 burner was obtained from Sesto and a heater body was designed and fabricated to accommodate it; the resulting heater is pictured in Figure 10. The triple-stage

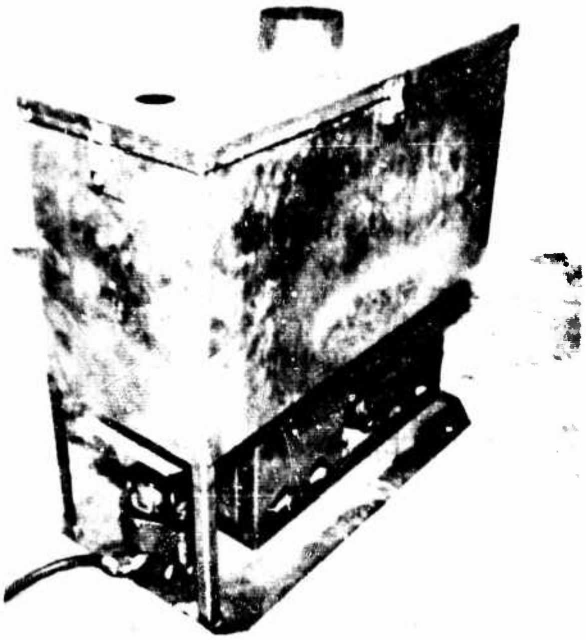
TABLE 5

Triple Stage Burner Data

CHARACTERISTIC	RECTANGULAR BURNER Type 1 (Dutch)	Type 2 (Dutch)	Type 3 (USA)	Type 4 (Dutch)	Round (USA)
Max. Design Capacity, ml/min Diesel Fuel	15	28.6	40	37.4	37
Top Opening mm x mm	60 x 400	90 x 400	100 x 500	90 x 550	63.5 dia. 677 circum.
Top Opening Area mm^2	24,000	36,000	50,000	49,500	43,000
Total Air Inlet Area mm^2	1673	2065	2888	3295	2466
First Stage:					
Hole Dia. mm	2.25	2.16	2.33	2.13	2.16
No. Holes	26	50	60	70	60
Area mm^2	103.4	183.2	256	250.2	220
% of Total Area	6.2	8.9	8.9	7.6	8.9
Second Stage:					
Hole Dia. mm	3.05	3.05	3.25	3.05	3.05
No. Holes	36	36	44	48	43
Area mm^2	263	263	368	350.2	316
% of Total Area	15.7	12.7	12.7	10.6	12.8
Third Stage:					
Hole Dia. mm	2.25	2.16	2.33	2.13	2.16
No. Holes	36	50	60	72	60
Area mm^2	143.1	183.2	256	257.4	220
% of Total Area	8.6	8.9	8.9	7.8	8.9
Burner Top:					
Hole Dia. mm	2.57/3.05	3.5/3.7	3.7/3.9	3.65/5.01	3.5
No. Holes	156	144	180	136/64	172
Area mm^2	1163.2	1435.2	2008	2437.6	1710
% of Total Area	69.5	69.5	69.5	74.0	69.3
Lower Baffle Opening mm^2	2541	2670	3520	5500	3206
Upper Baffle Opening mm^2	4006	4281	5450	4320	5090



Heater Lower Half



Assembled Heater

Burner With Baffles And Flame Spreader Removed

Figure 10. Type 2 Triple Stage Burner And Heater Body

burner feeds into a rectangular box 25.4 cm wide, 35.5 cm high, and 63.5 cm long. The top is removable for storage of all stack sections and draft diverter. The constant level valve is mounted under the overhang for physical protection and has a reflective heat shield. Heater overall dimensions are: width 25.4 cm, height 58.4 cm, length 63.5 cm. The burner is shown with the two baffles and the flame deflector removed. An observation hole is shown in the heater top; it was covered with a glass disc during tests. The weight is 25.4 kg (56 lb).

Performance was good; results are shown in Table A8. With all 3 fuels the heater burned quietly and most times very cleanly. The maximum diesel fuel rate at which clean burning was observed was 31.6 ml/min. Smoke readings of 6 and 4 were reached at the lower fuel rates with gasoline and diesel fuel, respectively. At the higher fuel rates, however, no higher than #3 smoke was recorded. Efficiency at the maximum clean-burning fuel rates ranged from 62% with gasoline to 64% with diesel fuel.

The capacity, however, is still too low. At 31.6 ml/min diesel fuel rate, with an efficiency of 64%, output is only 13.3 kW (45,550 Btu/hr). This is below the minimum goal of 14.7 kW (50,000 Btu/hr). Also, the heater body design does not permit burning solid fuel.

3. **Triple-Stage Heater, Type 3:**

As a result of the excellent performance of the type 2 triple-stage heater, an in-house effort was undertaken to build a larger capacity unit. This in-house effort was chosen in lieu of a contract with Sesto of Holland due to legal and procurement difficulties in a foreign R&D contract.

The type 3 burner was designed by scaling up the type 2 burner by about 40%, with a target diesel fuel input capacity of 40 ml/min. Comparison of the type 1 and type 2 burner dimensions and capacities also gave some idea of what geometric changes to make. Resultant dimensions of the type 3 burner are shown in Table 5. In Figure 11, a comparison of the type 2 and 3 burner units is shown as well as an overall view of the type 3 heater. The dimensions of the overall heater are the same for type 2 and 3 with the exception of height. The heater body was reduced in height from 35.5 to 27.9 cm, reducing the type 3 total heater height to 50.8 cm. With this shorter heater, stack sections only are stored in the heater interior for shipment; the flue cap is stowed next to the constant level valve as shown in Figure 11. Differences between type 2 and 3 heaters are the stack position on the top of the heater, the hinged front door with air shutter, the exterior fuel line, and position of the constant level valve. The weight is 24.3 kg (53.5 lb) including all stack sections.

Type 3 Burners Type 2 Type 3 Heater

Figure 11. Type 3 Triple-Stage Heater With Burner Comparison With Type 2

The performance was disappointing. The heater, first tested with diesel fuel, burned with considerable smoke and exhibited unstable burning at about 30 ml/min accompanied by a roaring noise. Opening the air shutter alleviated this problem, so it was theorized that the air inlet holes were too small. The air holes in the first, second, and third stages were enlarged so the air inlet area increase was 33%. The resulting performance was even worse, much smokier than before. Every fifth hole was plugged next, giving a 9% increase in area over the original design. Two tests were run with this hole configuration; one with the heater body normal and one with all possible air leaks sealed up. These tests are shown in Table A9. The performance was still not very good, with smoke readings exceeding 3 most of the time and the roaring noise still occurring. The difference in efficiency between the two tests can be attributed to higher percent CO_2 caused by less excess air in the test where air leaks were sealed.

Since the burner was fabricated using educated guesses in geometric scaling, and performance was poor in spite of several attempts to improve it, further testing was suspended.

4. **Round Triple-Stage Heater:**

A round triple-stage burner was designed and fabricated, intended as a replacement for the M41 pot burner. The burner exterior was designed exactly the same as the M41 pot burner.

As seen in Figure 12, there are 3 stages with air being supplied through holes in the burner body and the center section. Conceptually, the burner was designed as a rectangular triple-stage burner curled back upon itself. Design details are shown in Table 5. Where the air tube in the M41 pot burner acted only as a secondary air port and to some extent a flame spreader, the center section in this burner acts as a stage separator, air inlet device for each stage, and a substantial flame spreader.

Burner Pot **Insert**

Figure 12. Round Triple-Stage Burner

The performance of the round triple-stage burner, indicated by data of Table A10, is quite good. It appears, however, that above a 40-ml/min fuel input rate, the burner is overfired and excess smoke results. Also, in low fuel flow rates (6 to 15 ml/min) the fire is too smoky. Overall, with all three fuels, the smoke readings for fuel rates of 20 to 40 ml/min were excellent, with efficiency at maximum fire ranging from 53% for gasoline to 55% for diesel fuel.

In comparison to the standard M41 heater, the smoke readings for the round triple-stage heater were higher from 10 to 25 ml/min, but lower for 25 to 45 ml/min fuel flow, for all three fuels.

Soot deposition in this burner is a big problem After several hours of burning, some air holes became closed up with a porous layer of soot and would eventually plug up completely. Typical appearance after a test is shown in Figure 13.

Figure 13. Soot Deposition On Round Triple Stage Burner

Several attempts to eliminate soot deposition by modifying air holes at stages 1 through 3 did not result in any improvement. It is obvious that the performance of the burner would degrade, once substantial soot deposition took place.

For the tests in Table A10, the burner was cleaned prior to each test.

5. Variable-Air Pot Burner:

In reference 5, it was indicated that an optimum firing rate exists for minimum smoke formation in the M41 pot burner. This rate, expressed as an air/fuel weight ratio, is 30 to 1. The air/fuel ratio in the M41 heater ranges from 16 to 1 to 60 to 1.

Early in the heater study, it was felt that heater performance could be improved by maintaining an air/fuel ratio near the optimum 30 to 1 figure. To test this hypothesis, a variable-air pot burner, pictured in Figure 14, was designed and fabricated.

Figure 14. Variable-Air Pot Burner

The design is patterned after the M41 pot except each row of holes was replaced with slots. The slots were sized to be able to maintain the 30 to 1 air/fuel ratio at the highest fuel flow rate. For lesser fuel flow rates, each slot could be lessened in length by rotation of a tightfitting outer shell with corresponding slots. Thus, air inlet area could be infinitely varied from zero at complete slot interference, to full at complete slot match up.

Tests were carried out using gasoline at various slot settings, with poor results. The lowest smoke reading in any test was No. 7, and often heavy smoke (9+) was emitted. Test results are not included in this report.

As concluded in reference 5, the role of the holes in the M41 pot burner is not only to bring in primary air, but also to drive a recirculatory flow which mixes combustion products with the freshly vaporized fuel. It appears that the slotted variable air burner did not achieve the necessary recirculatory flow.

Due to the poor results achieved at all slot settings, no further work was done with this burner.

6. M41 with Extended Body:

Since the thermal efficiency of the M41 heater suffers due to a small heated surface area, an extender cylinder of 16 gage steel 45.7 cm in diameter and 24.1 cm high was inserted between the lower and upper sections. The "extended" heater is pictured in Figure 15.

With the extender in place, the heated surface area was doubled. Two tests (data not included in this report) were run one after the other, in which the extender was used in one test, and not used in the other. With the extender added, stack temperature was 16% lower, draft about 20% lower, and percent CO_2 and smoke had no appreciable change. The thermal efficiency increased between 6 and 7% for the extended heater.

It must be pointed out, however, that the addition of the extender lowers the temperature of the top surface of the heater by an average of 15.5%. Since radiant heat

Figure 15. M41 Heater With Extended Body

transfer depends upon the fourth power of the absolute temperature, comparison of radiant energy emitted for several fuel flow settings indicates the top surface of the standard M41 heater radiates 70% more heat. The sides of the extended heater, although somewhat lower in temperature than the standard heater, put out much more radiant energy due to the doubled surface area. Although the difference in the radiant/convective heat transfer ratio for the two heaters cannot be quantitatively compared, it is known that, for the extended heater, 6 to 7% more heat is put out.

Whether the economic or logistic viewpoint would favor the material, bulk, cost, and weight of the extender to increase efficiency by 6 to 7% is debatable.

7. Triple-Stage Heater, Type 4:

On 7 November 1977 a contract was awarded to Sesto Research Institute, Hilversum, Holland, to supply a triple-stage burner and provide services to install it in a Government-furnished heater body. The resulting heater was to have a diesel fuel input capacity of 37 ml/min and be capable of burning gasoline, kerosene, and diesel fuel noiselessly with zero smoke readings over the entire operating range.

Due to difficulties in achieving the desired performance using the supplied type 3 heater body (pictured in Figure 11), Sesto made up their own heater body, as shown in Figure 16. The shape of the heater body is very similar to the Type 1 triple-stage heater. Dimensions of the heater cage are: Length 83.2 cm, width 40.2 cm, and height 69.5 cm, and the weight of the heater packed for transit is 55.3 kg (122 lb). The heater body, not including protrusions, is 62.5 cm long, 20.5 cm wide, and 58.5 cm high, and weighs 23.4 kg (51.5 lb). The top opening of the triple-stage burner is 90 mm by 550 mm; further details of the burner are given in Table 5.

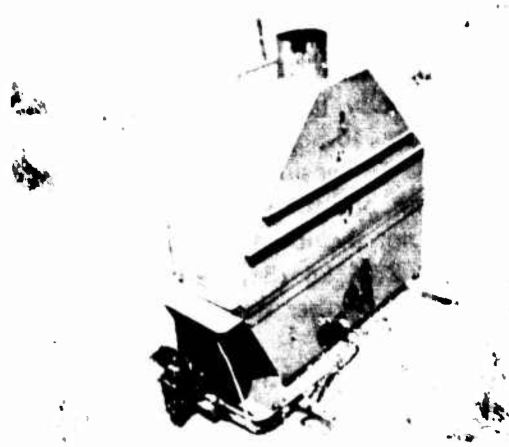
The performance of the heater was generally excellent, as indicated by data in Table A11. This is by far the cleanest burning heater tested, with the majority of smoke readings zero.

At maximum firing rates, this heater operates with 54% excess air, almost double that of the M41, and considerably more than the type 2 and 3 triple-stage heaters. This causes a lower CO_2 percent and a higher stack temperature, both of which contribute to a lower efficiency. Efficiencies at maximum fire range from 53% for diesel fuel to 59% for gasoline.

One subtle difference between this heater and the type 1 triple-stage heater is the addition of a heat shield around the sides and bottom of the burner. Both type 1 and type 4 heaters have an explosion hatch. This is a hinged door located on a slanted surface, held in the closed position only by gravity. The door also contains a hole with sight glass to see into the heater interior.

In the contract with Sesto, the type 3 triple-stage heater body was supplied as Government Furnished Property (GFP) because it had several desirable features and was the right size and shape to accept a triple-stage burner. Features of this GFP heater body which were not provided in the Sesto-designed type 4 heater were the door with air shutter providing solid fuel capability, the flat top providing ration/water heating capability, and the internal storage of five stack sections. In order to provide storage for the stack sections, Sesto had to add the screen inclosure which adds about 30 kg to the weight of the heater unit.

Packed For Transit



Heater Less Protective Screen

Upper & Lower Halves; Baffles Removed

Figure 16. Type 4 Triple-Stage Heater

The maximum output of the heater, from data in Table A11, is summarized in Table 6.

TABLE 6

Maximum Output of Type 4 Triple-Stage Heater

Fuel	Maximum Fuel Rate (ml/min)	Fuel Input kW	Fuel Input Btu/hr	Smoke (Bach.)	Efficiency (%)	Heat Output kW	Heat Output Btu/hr
Gasoline	40.4	23.6	80,580	5	59	13.9	47,550
Kerosene	40.0	24.5	83,730	3	56	13.7	46,890
Diesel	37.5	24.7	84,470	4	53	13.1	44,770

It is interesting to compare this data with that of Sesto, as shown in Table 7:

TABLE 7

Sesto's Test Results for Maximum Output of Type 4 Triple-Stage Heater

Fuel	Maximum Fuel Rate (ml/min)	Fuel Input kW	Fuel Input Btu/hr	Smoke (Bach.)
Gasoline	39.5	23.3	79,570	0+
Kerosene	39.5	24.2	82,680	0+
Diesel	37.4	24.7	84,250	0+

Sesto did not provide data on stack gas temperatures so efficiency and heat output could not be calculated. For fuel flows nearly identical to ours, Sesto measured 0+ smoke, compared to our readings of 3 to 5. No apparent reason can be found for the difference.

It is interesting to compare the type 2 and 4 triple-stage heaters at a diesel fuel input rate of 31.6 ml/min; this is near maximum capacity, and smoke readings are 2 and 1, respectively. The type 4 heater has about a 10% higher stack temperature and a 32% lower CO_2 percent than the type 2 heater. This results in a type 4 efficiency of 48.5% compared to 63% for type 2. Both heaters use a Sesto-designed burner; the type 4, however, has a Sesto-designed heat exchanger, whereas the type 2 has a NARADCOM-designed heat exchanger. The type 4 heat exchanger has about 30% less heater surface area and a much narrower flame spreader, resulting in a higher stack gas temperature. The type 4 heater has nearly triple the excess air at this specific flow rate.

It is not clear why the type 4 heater, completely designed and fabricated by Sesto of Holland, operates with this much excess air. Perhaps with this burner design, substantial excess air is necessary to achieve clean burning at diesel fuel flow rates as high as 37.5 ml/min. Redesign of the heat exchanger and flame spreader can lower stack temperature and some reduction of excess air can probably be accomplished in a redesign without increasing smoke output. If these steps increase the efficiency at maximum diesel fuel rate (37.5 ml/min) by only half the above difference (7.25%) the maximum heat output would be 14.9 kW (50,890 Btu/hr) which exceeds the goal of 14.6 kW (50,000 Btu/hr) maximum output.

The type 4 triple-stage heater is superior in performance to any heater tested in regard to smoke output. However, with its present shape, weight and relatively low efficiency, it cannot be considered as a replacement for existing military heaters.

CONCLUSIONS

The idea behind the M50 (Yukon Stove) is very good. It is simple, inexpensive, easily mass-produced, lightweight, completely self-storing and very compact, capable of burning solid fuel or liquid fuel, and throws out a lot of heat. However, the combustion is carbonic and excessive smoke is produced with any liquid fuel. The heater is designed only for gasoline, but is used with whatever fuel is available, often diesel fuel. With diesel fuel, the problems of difficult starting, incomplete combustion, excessive soot deposition, and horrible exhaust gas odor are cause for many complaints. In additon, the heater is dangerously unstable and easily knocked over and apart, and noisy in operation. Many users appreciate the noise the M50 makes, however, as an indicator of whether the heater is in operation.

The M41 heater achieves a mixture of carbonic and hydroxylative combustion, the percentage of each depending upon the fuel burned and the fuel flow rate. The M41 achieves poor to moderate smoke readings, and suffers from a small heated surface area and a relatively low efficiency. It is much more rugged than the M50, but no provision is made for self-storage of all components. It is clumsy to transport, and stack sections are often badly dented in transit. The M41, however, is physically stable and quiet in operation.

A summary of the performance of several heaters with diesel fuel is given in Table 8. This table is limited to diesel fuel for clarity and because it is the most difficult fuel to burn. With the current trend of "dieselization" of field equipment, any proposed space heater must be able to burn diesel fuel cleanly.

The heaters are arranged in Table 8 in ascending order of thermal efficiency. Not included in this table is the UK 10–kW gasoline heater, the extended M41 heater, and the variable-air pot burner. The UK 10–kW gasoline heater is not designed for use with diesel fuel and was not tested with it. It is a very interesting design but is too low in capacity and lacks the multifuel capability. The extended M41 heater has all the liabilities of the standard M41, only it has a higher efficiency due to lower stack temperatures. The variable-air pot burner is experimental and did not perform well enough to warrant further consideration.

The Kawabe 800S heater is much too low in output to compare it with the M41 or M50. The double-flow design with exterior fins does not appear to result in a highly efficient heater mainly due to the very large amount of excess combustion air. The burner performance with regard to smoke is excellent at the maximum firing rate of 15.8 cc/min, with a smoke reading of only 2.

The LWL Experimental Heater, in spite of all its gadgetry and alleged improvements, did not perform well at all with any fuel. This result, coupled with the poor performance of the M50, seems to indicate that the absence of staged oxidation or recirculatory flow in a burner permits carbonic combustion to dominate. Many attempts to improve the

TABLE 8

Summary of Heater Performance with Diesel Fuel

HEATER	Thermal Efficiency (%)	Fuel Flow (ml/min)	Heat Output (kW)	Heat Output (Btu/hr)	Smoke Number (Bach)	Excess Air (%)	Heated Surface Area (cm^2)
	At Maximum Fire With Diesel Fuel						
Type 1 Triple-Stage	48	15	4.7	16,220	1	123	2990
Kawabe 800 S	51	15.8	5.3	18,150	2	162	7056
M41	52	37.5	12.9	43,920	5 to 8	40	3460
Type 4 Triple-Stage	53	37.5	13.1	44,770	4	54	5470
M41/Rd. Triple-Stage	55	37	13.4	45,840	1	34	3460
LWL Experimental	56	38.7	14.3	48,900	9+	54	5677
Orchard Heater	57	≈60	22.6	77,000	4	34	5972
Type 3 Triple-Stage	59.5	35.3	13.9	47,310	5	44	6573
Type 2 Triple-Stage	64	31.6	13.3	45,380	2	34	7942
M50, Yukon Stove	71	34.5	17.6	59,980	9+	7	6500
	73	53	25.5	87,150	9+	4	

M50 burner have been made over the years, such as the introduction of swirl at the air inlet, introducing holes in the vaporizing plate to get more air into the flame envelope, etc. In all modifications, the air for combustion entered all at once in the vicinity of the vaporizing plate. The fuel can only flash into carbonic combustion, thus dooming the heater to a smoke-spewing existence.

The return-stack orchard heater demonstrated the positive benefits obtained from exhaust gas recirculation, but its design is not at all applicable for field space heating. The return-stack concept should be further investigated for field space heating.

There were five triple-stage heaters tested. The type 1 triple-stage heater has the lowest efficiency of all heaters tested, but it should be noted that only very limited testing was done with this heater prior to the burner being mistakenly discarded. The small heated surface area contributed somewhat to the low efficiency, however, but the primary cause is too much excess air. The smoke output for the type 1 triple-stage heater is impressively low. The low output of the heater, and about one-third of what we want, led us to acquire and test larger versions. The type 2 triple-stage heater, consisting of a larger triple-stage burner in a NARADCOM-designed heater body, performed very well. It burned cleanest with kerosene, and somewhat dirtier with gasoline and diesel fuel. Sesto Research Institute, from whom the burner was obtained, claimed the burner should operate with zero smoke. Also, in wind gusts, the heater would emit a low roaring noise at higher fuel flow rates. Unfortunately, the maximum output with diesel fuel was only 13.8 kW (46,980 Btu/hr). This, coupled with the unstable burning and roaring noise in gusts, led us to believe the burner capacity was just too low.

The type 3 triple-stage heater features a NARADCOM-designed burner with larger capacity, and an improved NARADCOM-designed heater body. Initial tests revealed quite poor performance and unstable burning at the maximum design rating of 40 ml/min input diesel fuel. The air holes were modified several times with little success toward achieving clean burning up to the desired 40 ml/min input.

The type 4 triple-stage burner was designed and fabricated by Sesto under contract. Sesto's test results indicated 0 or 0+ smoke readings over the entire burning range with all three fuels. Our test results indicated 0 to 2 smoke over the entire burning range with all three fuels with the exception of the maximum firing rate where smoke readings of 3 to 5 were obtained. The type 4 triple-stage heater is the cleanest burning heater tested, especially with diesel fuel. The excessive weight of the type 4 triple-stage heater, the inability to burn solid fuel in an emergency, and the sloping top, all are deficiencies that indicate a need for redesign of the heater body.

A comparison of the performance of the type 4 triple-stage heater with the M50 and M41 is presented in Figure 17. The triple-stage heater is clearly superior in regard to smoke output. The efficiency of the triple-stage heater is comparable to that of the M41 at higher fuel flow rates, but is much lower than that of the M50. It appears that the achievement of low smoke readings caused by very complete combustion necessarily

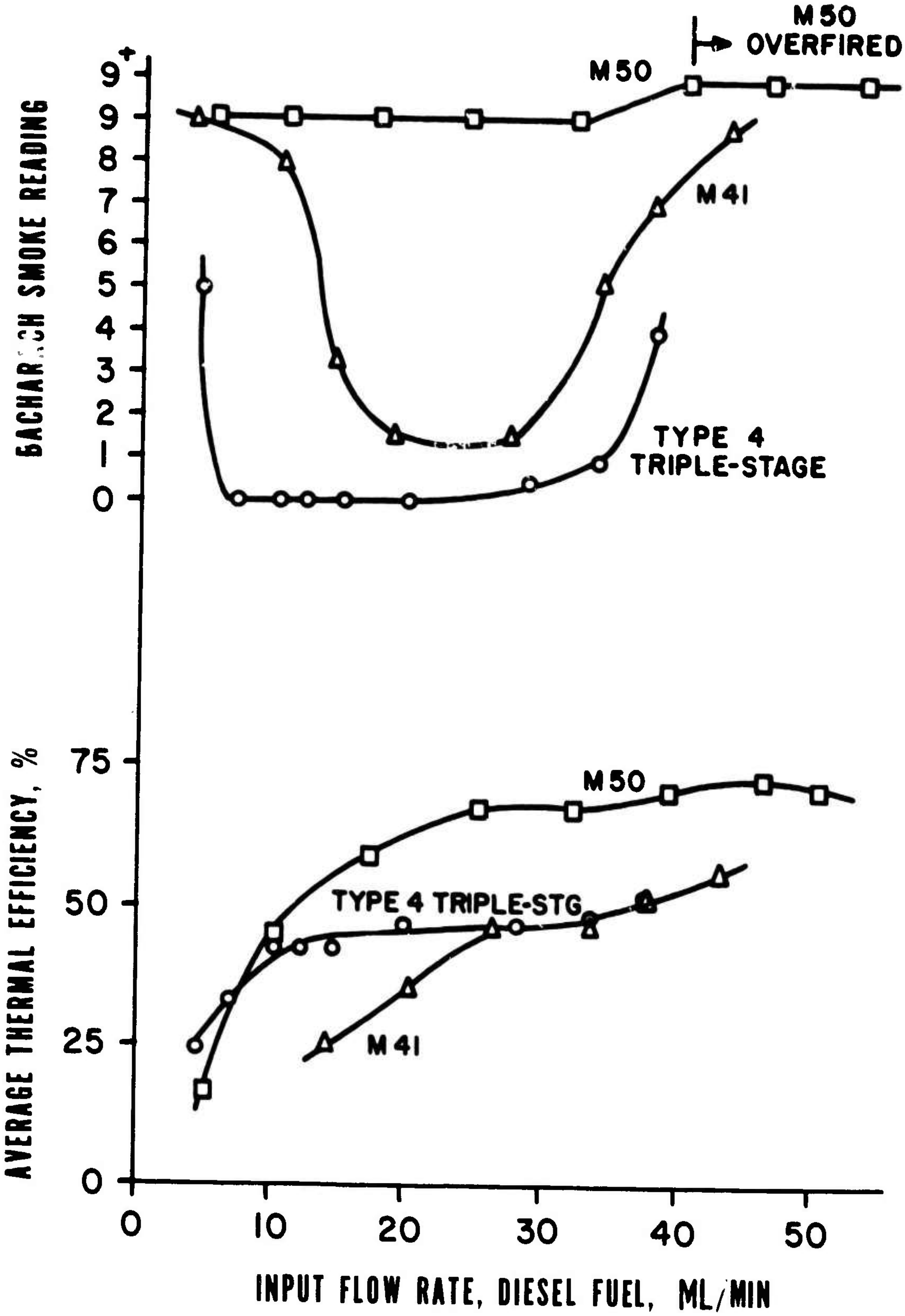


FIGURE 17. COMPARISON OF M41, M50 AND TYPE 4 TRIPLE-STAGE HEATERS, EFFICIENCY AND SMOKE OUTPUT USING DIESEL FUEL.

demands more excess air than the carbonic-type M50 heater. This excess combustion air lowers the efficiency. Also, no triple-stage heater can expect to get the excellent coupling between the hot gases and the heater surfaces exhibited by the M50, over such a large surface area. The M50 is the most efficient heater design tested, and this is borne out by the data. For field heaters, however, efficiency is not the most important aspect of performance. A clean-burning heater, which does not produce objectionable smoke and soot deposits, is more important to a soldier than an abstract notion such as efficiency.

The candidate heaters with the most promise appear to be a modified type 4 triple-stage heater and a heater with an exhaust gas return stack yet to be designed and fabricated.

This document reports research undertaken at the US Army Natick Research and Development Command and has been assigned No. NATICK/TR–79/021 in the series of reports approved for publication.

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APPENDIX A
TEST DATA

TABLE A1

Heater: M41
Fuel: Gasoline
Fuel Temp. Test 1: −1°C
Test 2: 12°C

	Fuel Flow	Draft				Temperatures, °C			Air			Thermal
Setting	Rate ml/min	Pa	In. H_2O	CO_2 %	Smoke Bach.	Stack	Avg. Body	Base	Shltr	Amb.	Wind M/S	Efficiency %
Test #1												
1	4.6	8.7	0.035	1.5	9	177	118	54	20	−1	<0.9	44
2	15.0	13.7	0.055	4.0	4	399	263	77	20	−1	<0.9	47
3	18.2	14.9	0.06	5.5	2	504	316	116	20	0	<0.9	49
4	23.1	18.2	0.073	6.5	1	649	393	121	20	0	<0.9	44
5	2[illegible]7	18.7	0.075	8.0	1	671	416	132	20	0	<0.9	51
6	33.3	19.9	0.08	8.0	1	771	466	143	20	0	<0.9	45
7	40.0	22.4	0.09	9.5	3	>816	527	143	20	0	<0.9	49
8	No Readings											
9	48.0	22.4	0.09	10.5	3	>816	557	154	20	0	<0.9	53
Test #2												
1	6.7	11.2	0.045	1.5	9	221	154	93	20	3	<0.9	30
2	15.0	14.9	0.06	3.5	5	404	266	110	20	3	<0.9	40
3	20.7	16.9	0.068	5.5	1	566	352	127	20	3	<0.9	44
4	23.5	18.7	0.075	3.0	1	604	371	129	20	3	<0.9	44
5	28.6	21.2	0.085	7.0	1	721	429	132	20	3	<0.9	42
6	36.0	21.2	0.085	8.0	1	816	460	138	20	3	<0.9	42
7	41.4	22.0	0.088	10.5	2	>816	514	143	20	3	<0.9	53
8	No Readings											
9	50.0	22.4	0.09	12.0	5	>816	545	154	20	3	<0.9	57

TABLE A1
(Cont'd)

Heater: M41
Fuel: Gasoline

Setting	Fuel Flow Rate ml/min	Draft Pa	Draft In. H_2O	CO_2 %	Smoke Bach.	Temperatures, °C Stack	Avg. Body	Base	Air Shltr	Air Amb.	Wind M/S	Thermal Efficiency %
Test #3												
1	5.9	8.7	0.035	1	7	188	154	NM	19	12	1.3	15
2	11.5	12.4	0.05	2	[illegible]	266	199	NM	21	12	1.6	35
3	16.2	13.7	0.055	2.5	2	371	260	NM	18	12	1.3	26
4	18.8	13.7	0.055	3.5	1	449	299	NM	18	12	1.6	34
5	27.3	14.9	0.06	5	1	523	371	NM	20	12	1.8	36
6	30.0	16.2	0.065	6.5	5	682	427	NM	21	13	1.8	42
7	40.0	17.4	0.07	8.5	8	771	504	NM	23	13	2.2	47
8	42.8	18.7	0.075	10	9	>816	538	NM	28	13	1.1	51
9	46.2	18.7	0.075	11	9	>816	554	NM	32	13	1.3	55
Test #4												
1	4.4	7.5	0.03	.5	9+	132	110	66	19	18	3.6	–
2	10.0	10	0.04	1.5	6	254	199	71	21	18	1.8	20
3	16.2	12.4	0.05	3	2	354	282	82	22	18	2.2	40
4	21.4	13.7	0.055	4.5	0	454	338	88	23	18	1.3	46
5	28.6	14.9	0.06	5.5	2	560	399	93	24	19	1.8	45
6	31.6	16.2	0.065	6.5	7	627	466	110	28	18	1.8	47
7	40.0	17.4	0.07	9.5	6	727	504	116	30	19	0.9	55
8	42.8	17.4	0.07	10	9	766	538	129	34	19	1.6	54
9	46.2	18.7	0.075	11	9	771	577	143	37	19	1.3	57

TABLE A1
(Cont'd)

Heater: M41
Fuel: Kerosene
Fuel Temp. Test 1: −7.2°C
Test 2: −4.4°C

Setting	Fuel Flow Rate ml/min	Draft Pa	Draft In. H_2O	Co_2 %	Smoke Bach.	Temperatures, °C Stack	Temperatures, Avg. Body	Temperatures, Base	Air Shltr	Air Amb.	Wind M/S	Thermal Efficiency %
Test #1												
1	4.4	9.6	0.04	1.5	9	166	113	60	20	−2	2.7	47
2	10.9	13.7	0.055	3.25	3	349	238	104	20	−1	1.8	43
3	18.2	17.4	0.07	5.75	1	532	342	127	20	−1	1.3	48
4	21.4	18.2	0.073	6.5	1	616	385	132	20	0	1.8	46
5	26.1	19.9	0.08	9.25	1	704	450	146	20	0	1.3	53
6	33.3	19.9	0.08	11.5	2	788	488	160	20	0	<0.9	56
7	40.0	22.4	0.09	10.25	3	>816	518	157	20	0	1.3	51
8	42.8	23.6	0.095	11.0	4	>816	538	154	20	2	<0.9	53
9	42.8	23.6	0.[illegible]5	12.0	6	>816	532	160	20	[illegible]	1.3	56
Test #2												
1	5.2	9.5	0.038	0	9	171	107	66	20	−6	1.1	–
2	11.3	13.7	0.055	.5	4	360	218	88	20	−6	<0.9	–
3	17.3	17.4	0.07	3.5	1	504	304	110	20	−4	1.3	25
4	21.2	18.7	0.075	5.25	1	604	349	121	20	−4	<0.9	37
5	26.1	19.9	0.08	7.0	1	693	400	138	20	−4	<0.9	43
6	30.0	21.1	0.085	7.25	2	774	463	143	20	−4	1.3	39
7	37.5	22.4	0.09	11.25	3	>816	513	149	20	−3	1.6	54
8	42.8	22.4	0.09	12.0	5	>816	543	166	20	−3	<0.9	56
9	44.0	22.4	0.09	12.5	6	>816	543	171	20	−1	1.8	57

TABLE A1
(Cont'd)

Heater: M41
Fuel: Kerosene & Diesel

Setting	Fuel Flow Rate ml/min	Draft Pa	Draft In. H_2O	Co_2 %	Smoke Bach.	Temperatures, °C Stack	Avg. Body	Base	Air Shltr	Air Amb.	Wind M/S	Thermal Efficiency %
Test #3	Kerosene											
1	2.4			0.5	9+	160	99		16	16	1.6	–
2	10.4			1.5	8	299	177		18	16	2.0	3
3	14.3			2.5	1	421	238		20	17	1.3	15
4	18.2			3.5	1	504	288		19	16	1.3	25
5	22.2			4.5	0	588	321		20	16	1.3	30
6	28.6			6	1	699	377		22	16	0.9	35
7	35.3			9	6	816	449		27	16	0.9	46
8	42.8			10	8	>816	493		31	16	0.9	51
9	46.8			12	9	>816	516		33	16	0.9	57
Test #1	Diesel Fuel											
1	3.0			0.5	9+	121	NM		22	18	<0.9	–
2	7.9			1.5	9	266	NM		23	18	1.3	14
3½	14.0			3	2	432	NM		25	18	1.3	25
5	18.8			4.5	1	493	NM		23	19	0.9	39
6	25			6	1	621	NM		23	20	2.2	41
7	33.3			7.5	7	721	NM		29	20	1.3	44
8	37.5			10.5	8	804	NM		28	21	1.8	52
9	42.8			11.5	9	>816	NM		32	22	0.9	54

TABLE A1
(Cont'd)

Heater: M41
Fuel: Diesel Fuel
Fuel Temp. Test 2: −3°C
Test 3: −8°C

Setting	Fuel Flow Rate ml/min	Draft Pa	Draft In. H_2O	Co_2 %	Smoke Bach.	Temperatures, °C Stack	Avg. Body	Base	Air Shltr	Air Amb.	Wind M/S	Thermal Efficiency %
Test #2												
1	3.5	10.0	0.04	0.5	9	166	118	85	20	−4	1.8	–
2	10.1	12.4	0.05	1.5	8	310	195	110	20	−3	1.8	–
3	18.2	15.7	0.063	3.5	1	482	288	110	20	−3	<0.9	26
4	19.4	18.7	0.075	5.0	1	568	335	121	20	−1	<0.9	36
5	22.2	18.7	0.075	5.5	1	632	361	132	20	−1	<0.9	35
6	27.1	18.7	0.075	8.5	2	727	414	138	20	−3	2.2	48
7	34.0	22.4	0.09	9.5	3	774	438	152	20	−3	<0.9	49
8	35.3	22.4	0.09	10.0	3	810	453	149	20	−4	1.8	49
9	37.5	21.2	0.085	10.5	5	>816	481	149	20	−7	<0.9	51
Test #3												
1	1.9	7.5	0.03	0.5	9	88	63	27	20	−6	<0.9	27
2	7.6	7.5	0.03	1.5	9	218	148	71	20	−4	1.1	28
3	14.0	14.9	0.06	3.0	3	421	271	93	20	−4	1.6	26
4	18.2	17.4	0.07	4.0	2	516	335	110	20	−3	<0.9	30
5	20.0	17.4	0.07	5.5	2	593	374	121	20	−3	<0.9	39
6	26.1	18.7	0.075	7.3	1	710	446	127	20	−3	1.1	43
7	33.3	19.9	0.08	9.5	3	816	503	138	20	−2	<0.9	47
8	37.5	19.9	0.08	10.0	6	>816	545	154	20	−2	<0.9	49
9	37.5	22.4	0.09	10.5	6	>816	554	171	20	−2	<0.9	52

TABLE A2

Heater: M50
Fuel: Gasoline
Fuel Temp. Test 1: – 2°C
Test 2: + 2°C

Setting	Fuel Flow Rate ml/min	Draft Pa	Draft In. H_2O	Co_2 %	Smoke Bach.	Temperatures, °C Stack	Avg. Body	Floor	Air Shltr	Air Amb.	Wind M/S	Thermal Efficiency %
Test #1												
	4.6	5.0	0.02	1.5	8	138	122	16	15	–2	1.3	55
	9.8	6.2	0.025	2.5	9	254	243	27	16	–2	<0.9	48
	17.1	7.5	0.03	5.5	8	371	682	49	20	–2	1.8	61
	25.0	10.0	0.04	7.5	7	427	406	60	27	–2	<0.9	66
	30.0	10.0	0.04	12.5	6	527	491	99	34	–1	3.6	72
	37.5	11.2	0.045	13.5	9	566	544	107	31	–1	1.8	71
	46.2	11.2	0.045	14.5	9+	599	568	107	34	2	<0.9	71
	54.6	12.4	0.05	15.0	9+	582	595	143	27	2	1.8	72
Test #2												
	5.3	6.2	0.025	3.5	6	182	174	27	14	–5	<0.9	70
	10.2	7.5	0.03	3.8	9	288	246	32	17	2	1.3	59
	16.7	8.7	0.035	5.0	9	360	343	54	22	0	<0.9	60
	24.0	10.0	0.04	9.5	5	460	462	77	26	1	1.8	69
	30.0	11.2	0.045	11.5	5	502	499	82	29	1	<0.9	71
	37.5	10.0	0.04	14.0	8	554	557	121	32	1	<0.9	72
	46.2	10.0	0.04	15.0	9+	554	599	121	36	1	1.3	74
	52.0	10.0	0.04	15.0	9+	521	597	123	38	1	<0.9	75

TABLE A2
(Cont'd)

Heater: M60
Fuel: Kerosene
Fuel Temp Test 1: 2°C
Test 2: 2°C

Setting	Fuel Flow Rate ml/min	Draft Pa	Draft In. H_2O	CO_2 %	Smoke Bach.	Temperatures, °C Stack	Avg. Body	Floor	Air Shltr	Air Amb.	Wind M/S	Thermal Efficiency %
Test #1												
	6.1	5.0	0.02	1.0	8	166	156	27	24	−1	<0.9	26
	10.8	7.5	0.03	2.5	9	316	277	38	14	−1	1.3	34
	16.6	10.0	0.04	5.0	9	404	362	54	19	−1	2.2	54
	23.1	12.4	0.06	8.0	9	454	443	77	27	−1	2.2	65
	31.6	12.4	0.06	11.5	8	504	518	110	27	0	2.2	70
	37.5	10.0	0.04	15.0	9+	549	580	132	36	0	1.8	73
	46.2	12.4	0.05	15.0	9+	516	596	138	33	3	<0.9	75
	50.0	10.0	0.04	14.0	9+	516	594	138	34	2	1.3	74
Test #2												
	5.6	6.2	0.025	2.0	7	188	171	38	11	−11	1.8	51
	9.6	6.2	0.025	2.5	9	271	246	38	13	−11	<0.9	43
	17.6	6.2	0.035	5.0	9	438	375	52	18	−11	1.3	51
	24.0	10.0	0.04	9.5	8	493	471	77	27	−10	1.8	67
	31.6	10.0	0.04	11.5	8	532	506	82	36	−10	1.3	69
	37.5	11.2	0.045	14.0	9+	599	577	99	23	−10	2.2	70
	46.2	11.2	0.045	12.5	9+	621	602	107	23	−9	1.3	66
	50.0	12.4	0.05	14.0	9+	62[illegible]	60[illegible]	116	27	−9	<0.9	69

TABLE A2
(Cont'd)

Heater: M50
Fuel: Diesel
Fuel Temp. Test 1: –8 °C
Test 2: 14 °C

Setting	Fuel Flow Rate ml/min	Pa	Draft In. H_2O	Co_2 %	Smoke Bach.	Temperatures, °C Stack	Avg. Body	Floor	Shlt.	Air Amb.	Wind M/S	Thermal Efficiency %
Test #1												
	5.1	5.0	0.02	1.0	9	171	158	38	22	–7	1.8	21
	10.0	7.5	0.03	4.5	9	349	313	49	24	–6	2.7	56
	16.7	10.0	0.04	6.0	9	393	374	82	27	–4	2.2	61
	25.5	10.0	0.04	9.5	9	449	461	82	26	–6	1.3	69
	31.6	8.7	0.035	12.5	9	516	537	121	23	–5	1.3	70
	37.5	10.0	0.04	14.0	9+	549	587	154	26	–3	2.2	71
	46.2	11.2	0.045	14.5	9+	516	605	177	31	–4	1.8	73
	54.0	11.2	0.045	14.0	9+	532	607	182	32	–4	1.8	72
Test #2												
	5.1	5.0	0.02	1.0	9	171	162	38	20	0	1.8	20
	10.4	5.0	0.02	3.0	9	343	304	49	19	1	1.2	39
	17.6	10.0	0.04	6.5	9	404	387	82	20	1	4.5	62
	24.0	10.0	0.04	10.5	9	466	482	127	24	0	2.2	70
	31.6	12.4	0.05	10.5	9	493	532	138	22	0	1.8	68
	40.0	12.2	0.045	15.0	9+	552	583	182	27	0	<0.9	72
	46.2	11.2	0.045	15.0	9+	521	611	193	29	0	3.6	74
	52.0	11.2	0.045	15.0	9+	527	609	213	31	0	2.2	74

TABLE A3

Heater: Type 1 Triple Stage Heater (United Kingdom Paraffin Heater)
Fuel: Gasoline & Diesel Fuel

	Fuel Flow					Temperature, °C						Thermal
	Rate	Draft		Co_2	Smoke				Air		Wind	Efficiency
Setting	ml/min	Pa	In. H_2O	%	Bach.	Stack	Avg. Body	Base	Shltr	Amb.	M/S	%
Test #1	Gasoline											
2	7.0	7.5	0.03	2.0	2	310	NM	NM	20	(Assumed)	NM	24
4	14.3	11.2	0.045	5.5	0.5	504	NM	NM	20	NM	NM	49
6	21.4	13.7	0.055	9.5	1	671	NM	NM	20	NM	NM	57
Test #2	Diesel											
2	4.8	7.5	0.03	4.0	3	254	188	NM	20	(Assumed)	NM	63
4	10.0	8.7	0.035	4.5	3	449	316	NM	20	NM	NM	44
6	15.0	11.2	0.045	6.5	1	577	382	NM	20	NM	NM	48

NM = Not Measured

TABLE A4

Heater: United Kingdom 10 kw Gasoline Heater
Fuel: Gasoline

Setting	Fuel Flow Rate ml/min	Draft Pa	Draft In. H_2O	Co_2 %	Smoke Bach.	Temperature, °C Stack	Avg. Body	Base	Air Shltr	Air Amb.	Wind M/S	Thermal Efficiency %
Test #1												
1	4.6	5.0	0.02	2.5	9+	182	316	NM	20	11	NM	62
2	9.5	7.5	0.03	5.5	9+	282	482	NM	20	13	NM	70
3	15.4	10.0	0.04	8.5	9+	477	549	NM	20	15	NM	65
4	21.4	12.4	0.05	12	9+	677	604	NM	20	18	NM	63
5	24	14.9	0.06	14	9+	760	604	NM	20	20	NM	64
6	33.3	14.9	0.06	NM	9+	816	604	NM	20	24	NM	–

NM = Not Measured

TABLE A5

Heater: KAWABE Type 800S (Japanese)
Fuel: Gasoline
Fuel Temp. Test 1: 13°C
Test 2: 11°C

Setting	Fuel Flow Rate ml/min	Draft Pa	Draft In. H_2O	Co_2 %	Smoke Bach.	Temperatures, °C Stack	Avg. Body	Base	Air Shltr	Air Amb.	Wind M/S	Thermal Efficiency %
Test #1												
1	6.3	12.4	0.05	2.5	3	227	197	43	26	21	1.3	55
2	9.0	12.4	0.05	3.0	5	304	282	54	27	22	1.3	49
3	12.2	19.9	0.08	5.0	1	371	356	63	30	22	<0.9	60
4	14.0	19.9	0.08	5.0	0	416	388	60	28	22	0.9	55
5	16.2	17.4	0.07	7.5	0	429	429	71	31	23	<0.9	66
6	17.6	22.4	0.09	9.5	6	466	454	66	32	23	1.3	69
7												
8												
9												
Test #2												
1	6.4	12.4	0.05	3.5	4	204	189	38	16	11	0.9	67
2	8.7	14.9	0.06	3.5	5	277	256	43	19	12	0.9	58
3	12.5	16.2	0.065	4.5	2	354	331	49	21	13	2.7	57
4	17.6	17.4	0.07	7.0	0	416	399	43	22	13	0.9	65
5	19.4	19.9	0.08	8.5	0	466	450	49	22	11	2.2	66
6	22.2	19.9	0.08	10.5	3	499	486	54	26	12	0.9	69
7												
8												
9												

TABLE A5
(Cont'd)

Heater: KAWABE Type 800S (Japanese)
Fuel: Kerosene
Fuel Temp. Test 1: 6.0°C
Test 2: 16.0°C

Setting	Fuel Flow Rate ml/min	Draft Pa	Draft In. H_2O	Co_2 %	Smoke Bach.	Temperatures, °C Stack	Avg. Body	Base	Air Shltr	Amb.	Wind M/S	Thermal Efficiency %
Test #1												
1	4.2	12.4	0.05	3	2	NM	151	38	24	2	0.9	NM
2	5.5	12.4	0.05	3	0	NM	178	38	28	3	0.9	NM
3	5.2	14.9	0.06	3.5	2	NM	254	32	13	6	0.9	NM
4	14.0	19.9	0.08	5	1	NM	346	32	14	6	0.9	NM
5	16.2	17.4	0.07	6	0	NM	399	38	16	4	0.9	NM
6	19.4	18.7	0.075	7	1	NM	443	49	17	4	0.9	NM
7												
8												
9												
Test #2												
1	4.2	10.0	0.04	1.5	3	177	144	38	11	8	0.9	40
2	6.1	11.2	0.045	2.0	2	238	198	38	12	8	0.9	39
3	9.4	14.9	0.06	3.0	3	321	276	38	13	8	0.9	43
4	13.0	17.4	0.07	4.5	2	393	347	41	13	7	1.2	51
5	16.2	19.9	0.8	6.5	0	443	407	41	16	7	0.9	59
6	18.8	21.2	0.085	8.0	2	482	416	43	20	7	0.9	63
7												
8												
9												

TABLE A5
(Cont'd)

Heater: KAWABE Type 800S (Japanese)
Fuel: Diesel
Fuel Temp. Test 1: 8°C
Test 2: 16°C

Setting	Fuel Flow Rate ml/min	Draft Pa	Draft In. H_2O	Co_2 %	Smoke Bach.	Temperatures, °C Stack	Avg. Body	Base	Air Shltr	Air Amb.	Wind M/S	Thermal Efficiency %
Test #1												
1	3.6	10.0	0.04	1.0	9	154	126	38	13	8	1.3	24
2	5.2	12.4	0.05	1.0	2	216	178	43	18	9	1.3	–
3	6.8	12.4	0.05	1.75	5	277	240	49	21	10	2.2	21
4	8.8	16.2	0.065	4.0	3	360	318	49	27	9	2.2	51
5	13.6	21.2	0.085	4.5	1	396	346	38	18	10	<0.9	50
6	15.8	18.7	0.075	4.5	2	427	375	32	19	9	1.8	47
7												
8												
9												
Test #2												
1	2.8	17.4	0.07	0	9	121	99	27	19	13	1.8	–
2	4.5	14.9	0.06	.5	8	177	145	32	20	12	0.9	–
3	7.0	14.9	0.06	2.0	5	232	218	41	18	13	2.2	40
4	10.2	18.7	0.075	2.5	4	327	298	43	19	13	0.9	32
5	13.3	24.9	0.10	4.8	2	377	355	49	19	13	0.9	55
6	15.8	24.0	0.10	5.5	1	421	402	54	20	13	1.8	55
7												
8												
9												

Table A6

Heater: Return Stack Orchard Heater
Fuel: Diesel (1½" Deep)

Primary Air Flow Air Holes Open	Draft		CO_2	Smoke	Temperatures, °C					Wind	Thermal Efficiency
	Fa	In. H_2O	%	Bach.	Stack	Avg. Body	Return Stack	Shltr	Amb.	M/S	%
Test #1											
1 Small	9.9	0.040	7.5	5	552	416	618	24	13	2.2	55
1 Sm; l Lg	11.2	0.045	9.5	4	716	450	716	33	13	1.2	53
2 Sm; l Lg	11.2	0.045	11.0	4	743	455	699	34	14	0.9	57
All Closed	9.9	.040	7.0	5	527	403	610	31	14	1.2	55

Table A7

Heater: LWL Experimental
Fuel: Gasoline
Fuel Temp. Test 1: 14.4°C
Test 2: 14.4°C

Setting	Fuel Flow Rate ml/min	Draft Pa	Draft In. H_2O	Co_2 c/o	Smoke Bach.	Temperatures, °C Stack	Avg. Body	Floor	Air Shltr	Air Amb	Wind M/S	Thermal Efficiency %
Low (SC)	13.5	14.9	0.06	4.0	9	371	316	43	22	17	<0.9	51
Med (SC)	34.3	17.4	0.07	13.5	9+	571	535	127	29	18	<0.9	71
Med (SO)	34.3	17.4	0.07	10	9+	588	461	93	29	18	<0.9	64
High (SO)	50.0	18.7	0.075	15	9+	704	574	166	35	19	<0.9	68

SC = Slots Closed
SO = Slots Open

Test #2												
Low (SC)	No Readings — Orifice In Valve Plugged Up											
Med (SC)	33.3	17.4	0.07	13	9+	571	528	127	31	21	<0.9	70
Med (SO)	33.3	17.4	0.07	9.5	9+	588	454	104	33	21	<0.9	62
High (SO)	50.0	18.7	0.075	15	9+	710	575	171	36	21	<0.9	68

Table A7
(Cont'd)

Heater: LWL Experimental
Fuel: Kerosene
Fuel Temp. Test 1: 4°C
Test 2: 9°C

Setting	Fuel Flow Rate ml/min	Pa	Draft In. H_2O	Co_2 %	Smoke Bach.	Temperatures, °C Stack	Ave. Body	Cook Screen	Air Shltr	Amb.	Wind M/S	Thermal Efficiency %
Test #1												
Low (SC)	15.5	18.7	0.075	4.5	9	432	306	193	14	−3	1.8	47
Med (SC)	30.0	19.9	0.080	10.0	9	643	486	354	14	−3	2.2	59
Med (SO)	30.0	19.9	0.080	7.0	9	538	463	321	22	−3	1.3	55
High (SO)	50.0	21.2	0.085	12.5	9+	749	564	477	24	−3	1.3	61
Test #2												
Low (SC)	12.8	17.4	0.07	4.0	9	399	296	160	17	−4	<1.0	46
Med (SC)	25.0	21.2	0.085	10.0	8	582	498	321	21	−3	<1.0	63
Med (SO)	28.6	19.9	0.08	7.5	9+	571	434	316	20	−3	<1.0	55
High (SO)	42.8	21.2	0.085	13.5	9+	749	557	460	29	−4	<1.0	63

SC = Slots Closed
SO = Slots Open

Table A7
(Cont'd)

Heater: LWL Experimental
Fuel: Diesel
Fuel Temp. Test 1: —4°C
Test 2: 1°C

Setting	Fuel Flow Rate ml/min	Draft Pa	Draft In. H_2O	Co_2 %	Smoke Bach.	Temperatures, °C Stack	Avg. Body	Cook Screen	Air Shltr	Amb	Wind M/S	Thermal Efficiency %
Test #1												
Low (SC)	14.0	17.4	0.07	4.5	9	438	324	193	16	–6	1.8	45
Med (SC)	25.0	24.9	0.10	9.0	9+	549	435	304	10	–6	4.5	60
Med (SO)	25.0	18.7	0.075	5.0	9+	466	393	254	11	–7	1.8	46
High (SO)	40.0	19.9	0.08	10.0	9+	671	553	438	26	–6	1.8	57
Test #2												
Low (SC)	12.8	18.7	0.075	2.5	9	371	278	166	8	–6	2.7	21
Med (SC)	24.0	21.2	0.085	9.0	9	571	456	310	12	–6	2.2	59
Med (SO)	24.0	18.7	0.075	5.5	9+	521	417	271	14	–6	2.2	45
High (SO)	37.5	21.2	0.085	9.0	9+	643	541	382	19	–6	5.8	55

SC = Slots Closed
SO = Slots Open

Table A8

Heater: Type 2 Triple Stage
Fuel: Gasoline & Kerosene
Fuel Temp. Test 1: 0°C
Test 2: 17°C

	Fuel Flow	Draft				Temperatures, °C						
Setting	Rate ml/min	Pa	In. H_2O	Co_2 %	Smoke Bach.	Stack	Avg. Body	Under Baffle No. 1	Air Shltr	Air Amb.	Wind M/S	Thermal Efficiency %
Test #1	Gasoline											
1	No Readings											
2	10.7	11.2	0.045	2.5	6	260	153	649	14	0	1.8	46
3	16.2	17.4	0.07	3.5	6	377	213	652	17	0	3.1	43
4	16.7	16.2	0.065	4.0	3	399	265	649	25	1	2.2	48
5	18.8	13.7	0.055	7.5	2	532	294	621	36	1	4.5	59
6	25.0	12.4	0.05	8.5	0	560	311	604	34	2	<1.0	61
7	35.3	14.9	0.06	10.5	0	654	370	588	32	2	3.1	62
8	42.8	16.2	0.065	10.0	8	704	411	582	18	3	3.1	57
9	42.8	17.4	0.07	11.5	9	682	424	588	21	3	3.6	62
Test #2	Kerosene											
1	No Readings											
2	9.4	11.2	0.045	1.5	1	260	159	546	16	8	<1.0	15
3	14.0	14.9	0.06	5	1.5	371	216	554	16	8	1.8	57
4	17.1	14.9	0.06	5	1	443	264	518	22	8	2.2	51
5	19.4	18.6	0.075	5.5	1	488	290	507	22	9	1.3	50
6	26.1	17.4	0.07	10	0	560	347	477	24	9	2.2	64
7	33.3	16.2	0.065	11.5	3	632	404	466	30	9	<1.0	64
8	42.8	17.4	0.07	12	9	693	468	449	36	9	<1.0	63
9	46.2	17.4	0.07	15	9+	654	478	493	36	9	<1.0	69

Table A8
(Cont'd)

Heater: Type 2 Triple Stage
Fuel: Diesel
Fuel Temp. Test 1: 11°C

Setting	Fuel Flow Rate ml/min	Draft Pa	Draft In. H_2O	Co_2 %	Smoke Bach.	Temperature, °C Stack	Temperature, °C Avg. Body	Temperature, °C Baffle No. 1	Temperature, °C Air Shltr	Temperature, °C Air Amb.	Wind M/S	Thermal Efficiency %
Test #1												
2	3.7	5.0	0.02	2.0	1	154	99	660	27	26	<1.0	62
3	7.8	10.0	0.04	4.0	2	249	154	713	27	27	2.7	65
4	10.2	10.0	0.04	4.5	4	310	192	710	29	27	3.1	61
5	14.3	10.0	0.04	6.0	4	388	242	704	32	28	2.0	62
6	18.2	10.0	0.04	7.5	3	460	280	699	34	28	2.2	63
7	25.0	6.2	0.025	9.0	2	532	299	677	36	28	1.8	63
8	31.6	14.9	0.06	11.0	2	604	344	660	37	28	1.8	64
9	35.3	14.9	0.06	14.5	9+	621	409	632	41	28	1.3	70

Table A9

Heater: Type 3 Triple Stage
Fuel: Diesel
Fuel Temp. Test 1: 6.1°C
Test 2: 13.3°C

Setting	Fuel Flow Rate ml/min	Draft Pa	Draft In. H_2O	Co_2 %	Smoke Bach.	Temperatures, °C Stack	Avg. Body	Burner Housing	Air Shltr	Air Amb.	Wind M/S	Thermal Efficiency %
Test #1												
1	5.0	7.5	0.03	1	7.5	104	76	77	24	7	1.8	54
2	9.8	11.2	0.045	4	7	282	141	110	19	7	5.4	60
3	15.8	14.9	0.06	4.5	8.5	316	192	160	23	7	1.3	60
4	16.5	13.7	0.055	5.5	5	393	216	171	30	7	2.7	59
5	18.2	14.9	0.06	4.5	5	410	211	166	20	8	5.8	49
6	21.4	19.9	0.08	5	4	443	239	171	17	9	6.7	49
7	27.3	14.9	0.06	7	1	541	295	166	19	9	1.8	53
8	33.3	19.9	0.08	8	3	599	338	171	19	9	5.8	54
9	35.3	18.7	0.075	8.5	4.5	604	342	177	20	9	5.8	56
Test #2												
1	4.4	7.5	0.03	1.5	9	149	76	60	18	13	0.9	50
2	10.0	12.4	0.05	3	9	277	132	104	19	13	0.9	50
3	14.6	14.9	0.06	4.5	8	377	191	143	22	14	0.9	53
4	18.8	16.2	0.065	5	5	421	224	160	22	16	0.9	52
5	19.4	16.2	0.065	5.5	5	466	240	166	24	16	0.9	51
6	25.0	17.4	0.07	8	3	521	287	182	26	15	0.9	60
7	28.6	18.7	0.075	9	1	538	322	188	26	14	0.9	62
8	35.3	19.9	0.08	12	6	654	367	188	31	16	0.9	63
9	40.0	21.2	0.085	13	9	654	379	199	33	16	0.9	66

TABLE A10

Heater: M41 With Round Triple Stage Burner
Fuel: Gasoline
Fuel Temp. Test 1: 6°C
Test 2: 9°C

Fuel Flow		Draft				Temperatures, °C			Air			
Setting	Rate ml/min	Pa	In. H_2O	Co_2 %	Smoke Bach.	Stack	Avg. Body	Base	Shltr	Amb.	Wind M/S	Thermal Efficiency %
Test #1												
1												
2	7.5	10.0	0.04	1.5	6	182	119	127	19	12	0.9	42
3	8.3	10.0	0.04	2.5	5	249	164	138	17	12	0.9	49
4	17.1	14.9	0.06	4.75	5	471	262	127	23	13	0.9	47
5	25.0	14.9	0.06	5	4	499	274	143	21	12	0.9	46
6	26.1	16.2	0.065	5.5	2	582	306	129	21	12	0.9	42
7	35.3	18.7	0.075	8.0	1	738	382	121	24	13	<0.9	47
8	40.0	19.9	0.08	9.75	5	793	416	110	26	12	0.9	52
9	42.8	19.9	0.08	11.75	7	>816	445	104	27	14	0.9	56
Test #2												
1												
2	7.1	10.0	0.04	0.5	7	210	128	121	19	18	<0.9	–
3	11.8	12.4	0.05	1.5	8	327	191	149	20	18	0.9	–
4	18.8	16.2	0.065	3.5	5	510	274	129	24	19	<0.9	26
5	22.2	16.2	0.065	4.0	4	566	293	132	23	13	<0.9	27
6	28.6	17.4	0.07	6.5	2	654	334	121	24	13	0.9	44
7	35.3	17.4	0.07	8.5	1	760	391	116	27	13	<0.9	48
8	40.0	18.7	0.075	10.5	4	>816	408	116	29	12	0.9	53
9	50.0	19.9	0.08	12.5	9	>816	469	99	31	12	0.9	59

TABLE A10
(Cont'd)

Heater: M41 With Round Triple Stage Burner
Fuel: Kerosene
Fuel Temp. Test 1: 18°C
Test 2: 1°C

Setting	Fuel Flow Rate ml/min	Draft Pa	Draft In. H_2O	Co_2 %	Smoke Bach.	Temperatures, °C Stack	Temperatures, °C Avg. Body	Temperatures, °C Base	Temperatures, °C Air Shltr	Temperatures, °C Air Amb.	Wind M/S	Thermal Efficiency %
Test #1												
1	No Readings											
2	No Readings											
3	16.6	14.9	0.06	4.5	4	482	260	157	20	4	<0.9	42
4	18.8	16.2	0.065	5.5	3	532	279	157	23	4	1.6	46
5	23.1	17.4	0.07	6.5	1	616	312	143	23	4	<0.9	46
6	30.0	19.9	0.08	8.5	0	727	366	127	21	4	2.2	49
7	37.0	21.2	0.085	10.5	0	804	406	121	26	4	2.7	53
8	43.5	21.2	0.085	12.5	6	>316	436	116	27	4	<0.9	58
9	46.5	21.2	0.085	13.0	6	>816	460	121	31	4	2.2	59
Test #2												
1	No Readings											
2	9.8	12.4	0.05	4.0	3.5	349	195	138	16	3	2.2	52
3	14.3	14.9	0.06	5.0	4	432	240	160	21	3	1.8	52
4	18.2	16.2	0.065	6.5	3.5	516	280	149	26	4	1.8	54
5	22.8	18.7	0.075	8.5	2	593	314	143	26	4	1.3	58
6	28.6	19.9	0.08	9.5	0	693	360	132	23	4	2.2	55
7	35.3	21.2	0.085	10.0	0	782	416	127	23	4	2.2	52
8	40.0	21.2	0.085	12.0	2	816	438	127	23	6	<0.9	56
9												

TABLE A10
(Cont'd)

Heater: M41 With Round Triple Stage Burner
Fuel: Diesel #2
Fuel Temp. Test 1: 5°C
Test 2: 3°C

Setting	Fuel Flow Rate ml/min	Draft Pa	Draft In. H_2O	Co_2 %	Smoke Bach.	Temperatures, °C Stack	Avg. Body	Base	Air Shltr	Air Amb.	Wind M/S	Thermal Efficiency %
Test #1												
1	No Readings											
2	6.7	10.0	0.04	3	7	210	130	110	16	1	1.3	61
3	10.9	12.4	0.05	4.5	6	349	203	149	18	1	<0.9	55
4	14.3	14.9	0.06	5	6	404	241	160	19	1	1.8	53
5	19.2	16.2	0.065	6	4	504	282	149	24	2	1.8	51
6	24.5	18.7	0.075	7.5	1½	610	323	138	25	2	1.8	51
7	29.3	19.9	0.08	8.5	1	660	345	127	27	3	<0.9	53
8	34.5	18.7	0.075	9	½	716	375	121	27	3	1.8	51
9	36.0	19.9	0.08	10	1	760	393	116	29	4	1.3	53
Test #2												
1	No Readings											
2	6.0	10.0	0.04	3	7	210	123	93	13	7	1.3	60
3	10.7	12.4	0.05	4	5	360	201	132	19	8	0.9	50
4	14.3	13.7	0.055	5.5	5	438	249	149	23	8	0.9	54
5	18.5	16.2	0.065	6.5	4	521	282	143	25	9	<0.9	53
6	22.2	17.4	0.07	8	2	604	316	138	26	10	1.3	54
7	29.3	17.4	0.07	9	1	671	353	127	24	12	1.3	54
8	35.3	18.7	0.075	10	½	760	386	116	28	12	0.9	52
9	37.5	19.9	0.08	12	1	782	414	116	28	12	1.3	57

TABLE A11

Heater: Type 4 Triple Stage
Fuel: Gasoline
Fuel Temp. Test 1: 19°C
Test 2: 20°C

Fuel Flow		Draft		CO_2	Smoke	Temperatures, °C			Air		Wind	Thermal Efficiency
Setting	Rate ml/min	Pa	In. H_2O	%	Bach.	Stack	Avg. Body	Base	Shltr	Amb.	M/S	%
Test #1												
1	6.7	7.5	0.03	1	3	227	139	21	23	22	<0.9	–
2	12.0	10.7	0.043	3	0	227	139	21	23	22	<0.9	46
3	14.6	11.9	0.048	4	2	354	229	43	25	23	<0.9	53
4	17.6	13.7	0.055	4	0	404	261	46	27	23	<0.9	47
5	20.0	13.7	0.055	5	0	443	285	49	28	24	<0.9	52
6	24.0	14.4	0.058	6	0	521	328	49	29	24	<0.9	52
7	33.3	16.2	0.065	9	0	638	384	49	29	24	<0.9	58
7.5	37.5	16.2	0.065	10	0	666	427	54	32	24	<0.9	60
8	42.8	17.4	0.07	10.5	7	710	460	57	32	24	<0.9	59
Test #2												
1	9.0	10.0	0.04	2	3	260	154	32	23	21	< .9	37
2	14.3	11.2	0.045	3.5	1	349	221	38	23	21	< .9	48
3	16.7	13.7	0.055	4.5	0	399	254	43	24	21	< .9	52
4	20.0	13.7	0.055	4.5	0	443	286	49	24	21	< .9	47
5	20.0	No Readings										
6	24.0	14.9	0.06	5.5	0	521	324	49	27	22	< .9	48
7	28.6	14.9	0.06	7	0	538	363	49	27	23	< .9	52
7.5	35.3	16.9	0.068	9.5	0	677	435	52	31	23	< .9	57
8	40.0	17.4	0.070	10.0	5	704	450	54	31	23	1.8	57

TABLE A11
(Cont'd)

Heater: Type 4 Triple Stage
Fuel: Kerosene
Fuel Temp. Test 1: 16°C
Test 2: 15°C

Setting	Fuel Flow Rate ml/min	Draft Pa	Draft In. H_2O	Co_2 %	Smoke Bach.	Temperatures, °C Stack	Avg. Body	Base	Air Shltr	Amb.	Wind M/S	Thermal Efficiency %
Test #1												
1	4.7	7.5	0.03	1	9	177	103	21	16	16	< .9	17
2	9.7	10.0	0.04	2	0	232	157	27	17	16	< .9	29
3	13.6	12.4	0.05	3.5	1	349	224	32	17	16	< .9	46
4	15.0	13.7	0.055	3.5	0	382	248	38	19	16	< .9	42
5	17.1	14.9	0.06	4	0	421	268	38	20	16	< .9	43
6	23.1	16.2	0.065	6	0	521	327	38	23	16	< .9	51
7	31.6	17.4	0.07	7.5	0	643	400	38	24	16	< .9	50
8	38.5	17.9	0.072	10	2	721	461	43	26	16	< .9	56
9	42.5	18.7	0.075	11.5	6	749	489	46	27	16	< .9	58
Test #2												
1	5.0	7.5	0.03	1	9	177	103	27	16	14	< .9	17
2	9.2	10.0	0.04	2.5	1	260	159	27	17	16	< .9	46
3	13.3	12.4	0.05	3.5	2	343	223	32	18	16	0.9	47
4	15.8	12.9	0.052	4	2	399	257	38	19	16	< .9	46
5	19.0	14.9	0.06	4.5	1	460	291	38	21	17	0.9	44
6	24.5	16.9	0.068	5	0	560	345	43	21	17	0.9	39
7	32.5	17.4	0.07	7	0	666	414	43	23	18	0.9	45
8	40.0	17.9	0.072	10	3	738	470	46	27	19	< .9	55
9	43.0	18.7	0.075	12	9	771	496	49	27	19	0.9	59

TABLE A11
(Cont'd)

Heater: Type 4 Triple Stage
Fuel: Diesel
Fuel Temp. Test 1: 17°C
Test 2: 18°C

Setting	Fuel Flow Rate ml/min	Draft Pa	Draft In. H_2O	Co_2 %	Smoke Bach.	Temperatures, °C Stack	Avg. Body	Base	Air Shltr	Air Amb.	Wind M/S	Thermal Efficiency %
Test #1												
1	3.9	6.2	0.025	1	6	154	96	21	18	18	0.9	27
2	7.0	8.7	0.035	1.5	0	227	134	27	18	17	< .9	25
3	10.0	11.2	0.045	2.5	0	293	184	32	18	17	1.8	38
4	12.0	12.4	0.05	3.0	0	338	216	38	19	19	0.9	40
5	14.6	13.7	0.055	3.5	0	382	246	38	20	20	1.3	41
6	19.7	14.9	0.06	5	0	488	298	38	22	19	< .9	45
7	28.6	16.2	0.065	7	½	610	371	38	23	19	0.9	48
8	33.3	17.4	0.07	8	1	682	428	38	23	19	< .9	49
9	37.5	17.4	0.07	9.5	4	721	460	43	24	19	0.9	53
Test #2												
1	3.9	6.2	0.025	1	4	149	86	21	19	19	< .9	30
2	7.0	8.7	0.035	2	0	216	128	21	19	19	< .9	44
3	10.3	11.2	0.045	3	0	277	177	27	20	19	< .9	50
4	12.0	11.9	0.048	3.5	0	327	216	38	21	19	< .9	49
5	14.3	13.2	0.053	4	0	388	243	43	21	19	< .9	46
6	20.0	14.4	0.058	5.5	0	488	306	43	23	20	< .9	49
7	27.3	16.2	0.065	7	½	610	367	43	22	20	< .9	48
8	33.3	17.4	0.07	8	1	677	420	43	24	19	< .9	49
9	37.0	18.2	0.073	9.5	4	721	445	43	25	20	< .9	53

APPENDIX B

HEATER THERMAL EFFICIENCY

Thermal efficiency, η, is defined as

$$\eta = \frac{\text{heat output}}{\text{heat input}} = \frac{\text{input-losses}}{\text{input}} = 1 - \frac{\text{losses}}{\text{input}} \qquad \text{(B1)}$$

Table B1 lists sources of heat loss for a typical residential oil burner operating at 10% CO_2 (from reference 2):

TABLE B1

Sources of Heat Loss

Source of Heat Loss	Percent of Total Heat Loss
1. Dry flue gases	62.2
2. Moisture formed by combustion of hydrogen in fuel	35.8
3. Incomplete combustion (formation of CO)	1.4
4. Moisture in air supplied for combustion	0.5
5. Moisture in fuel	0.1
	100.0

In precise laboratory procedures, all the above sources of heat loss would be included in the calculation of efficiency. However, for this report a shortcut method is used, based on the fact that the first two sources account for 98% of all losses. The commonly accepted method used to calculate efficiency for field applications is to include the first two heat losses, but assume combustion is complete. For this example, incomplete combustion is based on the percent carbon monoxide (CO) in the flue gases, which was listed as 0.07%. Incomplete combustion in this case causes only a 0.3% loss in combustion efficiency, but is for a well adjusted residential oil burner. For a smoky field space heater, the CO% would be higher and losses due to incomplete combustion would be greater. Except for the worst cases of poor combustion where the heater is overfired and accompanied by production of heavy black smoke, neglecting losses due to incomplete combustion is a reasonable approximation.

From reference 1 we find the constituents of gasoline, kerosene, and diesel fuel to be as indicated in Table B2.

TABLE B2

Fuel Constituents

	Weight Percent Carbon	Weight Percent Hydrogen	Average Molecular Formula
Gasoline	85.7	14.3	$C_8\ H_{16}$
Kerosene	85.7	14.3	$C_{11.6}\ H_{23.2}$
Diesel	85–86	14–15	$C_{14}\ H_{28}$

Complete combustion of gasoline can be written in molecular form as follows:

$$C_8\ H_{16} + 12\ O_2 + 45.1\ N_2 \rightarrow 8\ CO_2 + 8\ H_2O + 45.1\ N_2 \qquad (B2)$$

The coefficient for N_2 is calculated by noting that air is approximately 79% nitrogen and 21% oxygen; thus 3.76 moles of nitrogen accompany each mole of oxygen used in combustion.

The effect of percent excess air, E, on this equation is as follows:

$$C_8\ H_{16} + 12(1 + \frac{E}{100})\ O_2 + 45.1(1 + \frac{E}{100})\ N_2 \rightarrow 8\ CO_2 + 8\ H_2O$$
$$+ 12(\frac{E}{100})\ O_2 + 45.1\ (1 + \frac{E}{100})\ N_2 \qquad (83)$$

The ensuing analysis will be for gasoline only; identical results would be obtained for kerosene or diesel fuel due to the same carbon/hydrogen ratio in the average molecular formulas.

Heat loss due to flue gases, Lg, and due to water formed by the combustion of hydrogen, Lw, are calculated:

$$L = Lg + Lw$$

$$Lg = (WF)(C_{pf})(T_S - T_I)$$

where WF = weight fraction dry flue gas to fuel weight

C_{pf} = average specific heat of flue gases, $1.05 \frac{J}{g^\circ C}$

T_S = stack gas temperature, °C

T_I = temperature of inlet air supplied for combustion, °C

To calculate WF, use equation (B3):

$$WF = \frac{8(44) + 12(\frac{E}{100})\,32 + 45.1\left(1 + \frac{E}{100}\right) 28}{8(12) + 16} = 14.4 + \frac{14.7E}{100} \qquad \text{(B6)}$$

Note the molecular weight of CO_2 = 44, O_2 = 32, N_2 = 28. C = 12, H = 1.

It would be convenient to have Lg in terms of percent CO_2. Write percent CO_2 by volume from equation (B3):

$$CO_2 = 100\left(\frac{8}{8 + \frac{12E}{100} + 45.1(1 + \frac{E}{100})}\right) = \frac{800}{53.1 + 0.571E} \qquad \text{(B7)}$$

Solve for E:

$$E = \frac{1401}{CO_2} - 93 \qquad \text{(B8)}$$

Then

$$WF = 14.4 + 14.7\left(\frac{\frac{1401}{CO_2} - 93}{100}\right) = \frac{205.9}{CO_2} + 0.73 \qquad \text{(B9)}$$

Now we have

$$Lg = \left(\frac{205.9}{CO_2} + 0.73\right)(1.05)(T_S - T_I) \qquad \text{(B10)}$$

Calculation of Lw is as follows:

$$Lw = (HF)\left[C_{pw}\,(100 - T_I) + h_v + C_{ps}(T_S - 100)\right] \quad (B11)$$

where HF = amount of water formed per amount of hydrogen in fuel

C_{pw} = specific heat of water at 20°C = 4.18 $\frac{J}{g^\circ C}$

h_v = heat of vaporization of water = 2256.3 J/g

C_{ps} = specific heat of steam at 500°C = 2.09 $\frac{J}{g^\circ C}$

Note HF = (mol wt H_2O/mol wt H_2) (weight fraction H in fuel) = $\frac{18}{2}(0.143)$ = 1.287

$$\text{Then } Lw = 1.287\,(4.18\,(100 - T_I) + 2256.3 + 2.09\,(T_S - 100)) \quad (B12)$$

Efficiency can then be written in percent

$$\eta = \left(1 - \frac{Lw + Lg}{HHV}\right) 100 \quad (B13)$$

where HHV = high heating value of the fuel being input.

Values of HHV, taken from reference 1 are shown in Table B3.

TABLE B3

High Heating Values for Various Fuels

Fuel	HHV (J/g)
Gasoline	46 977
Kerosene	46 163
Diesel	45 116

Combining terms and simplifying, we get

$$\eta = 1 - \left[\frac{(3171 + 2.69T_S + \left(\frac{216.2}{CO_2} + 0.77\right)(T_S - T_I) - 5.38T_I}{HHV}\right] \quad (B14)$$

In the Appendix A data sheets, there are several places where thermal efficiency was found to be negative. These cases occurred at low fuel flow rates where very low percentages of CO_2 were recorded. Under conditions where the measured CO_2 percentage is 0 to 1.5, there is so much excess air that substantial errors may occur due to mixing

and sampling within the stack. Where negative efficiencics were found, dashes were written in the efficiency column.